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LOW COST MINIATURE DATA COLLECTION PLATFORM

CONTRACT NO. NAS5-22829



Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

APRIL 1977



American Electronic Laboratories, Inc.

A Subsidiary of AEL Industries, Inc.



P.O. Box 552, Lansdale, PA 19446 • Telephone 215-822-2929 • TWX: 510-661-4976 • Cable. AMERLAB

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SECTION 1

INTRODUCTION

1.1 SYSTEM ASPECTS

Signals transmitted from Data Collection Platforms (DCP) in various parts of the world are received, detected, and stored by a low-orbit satellite on a one-way link. When the satellite is in view of a ground station, the information is transmitted to the ground, and relayed to a ground data processing center.

The information obtained from the satellite is then extracted for users at a data processing center. Processing equipment detects each signal and extracts the frequency, time, platform signature, and sensor data. The extracted time information is referenced to the real time of receipt of the platform signals at the satellite. A computer algorithm is used to determine the position and/or velocity of each moving platform as is required.

1.2 SCOPE

Two earlier American Electronic Laboratory (AEL) programs associated with DCP's under NASA Contracts NAS5-21164 and NAS5-21633 paved the way for low cost, nominal efficiency, standard sized UHF units.

The objective of this program was to develop the various RF elements necessary to achieve a miniaturized data collection telecommunication package. The package should include significant reductions in complexity of the RF design to permit low cost reproducibility, while also meeting requirements for small size, weight, and minimum power supply elements.

The development of the RF elements of a telecommunications package involved detailed study and analysis of concepts and techniques followed by laboratory testing and evaluation of designs. The design goals for a complete telecommunications package excluding antenna is a total weight of 300 grams, in a total volume of 400 cm³ with a capability of unattended operation for a period of six months. Of utmost importance is extremely low cost when produced in lots of 10,000.

1.3 PERFORMANCE REQUIREMENTS

Indicated in the following table are the requirements for the RF elements in a Low Cost Miniature data collection telecommunication package. The antenna and digital circuitry were not a part of this program.

TABLE 1-1. TECHNICAL CHARACTERISTICS

Parameter	Specification
Frequency (includes dispersion and aging)	401.65 MHz $\pm$ 3.2 KHz
Frequency Stability	0.4 Hz per 0.120 Sec. $\pm$ 0.2 Hz per 20 Min. 400 Hz per 2 hrs.
Modulation	PSK, $\pm$ 63°
Power Output	3 watts $\pm$ 1 db
Spurious Output	-60 db within $\pm$ 20 KHz -25 db beyond $\pm$ 20 KHz
Temperature	-40°C to + 45°C
Operating Lifetime	6 Mos.
Weight/Volume	300 gms/400 cm ³
Cost	\$100 (10,000 lots)

SECTION 2

EXECUTIVE SUMMARY

2.1 GENERAL

The system block diagram of the RF elements in a Miniature Data Collection Platform is shown in Figure 2-1. In this text, the Miniature Data Collection Platform RF subsystem will be called simply MDCP. Early in the program it became apparent that a single MDCP would not satisfy all users. A single high-efficiency system would not satisfy a user who had available a large battery capacity but required a low cost system. Conversely, the low cost system would not satisfy the end user who had a very limited battery capacity. A system design to satisfy these varied requirements was implemented by designing several versions of the system building blocks shown in Figure 2-1 and then constructing three systems from these building blocks. These were designated MDCP 1, MDCP 2 and MDCP 3. Figure 2-2 depicts system MDCP1 which has an overall transmitter efficiency of 61%. This system has an output power amplifier efficiency of 75% which makes the unit ideal for many types of users. Figure 2-3 depicts a generalized system MDCP2 that requires no tuning and is therefore ideal for the oceanographer type user who generally has available a battery of large capacity. A correlation of characteristic tradeoffs between all three systems is shown in Table 2-1. Table 2-2 details the highlights of the highly efficient MDCP1 unit.

2.2 RESULTS

The following end results were determined through the study and analysis phases of this program:

- A highly efficient (61%), low current DCP system has been achieved, thus affording the many uses new grounds for long life experimentations.
- Low cost frequency stabilizing techniques over a -40°C to $+45^{\circ}\text{C}$ temperature range have been employed whereby adequate tracking accuracy can be obtained. This technique saves battery power and cost in that no crystal oven is required.
- Small size and reduced volume units are available at costs of \$350 ⁽¹⁾ in quantities of only 1,000.

⁽¹⁾Price includes digital and RF section but does not include batteries, enclosure or antenna.

- Physical size of battery cells for reasonable operating lifetime can work against miniaturization of electronics.
- Physical size of antenna is possible source of problems when using miniature platform package for a ground plane.

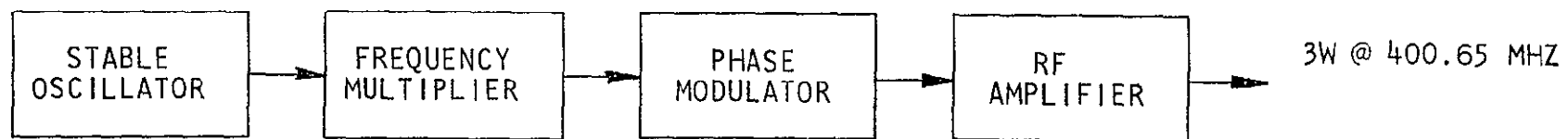


Figure 2-1. MDCP Block Diagram

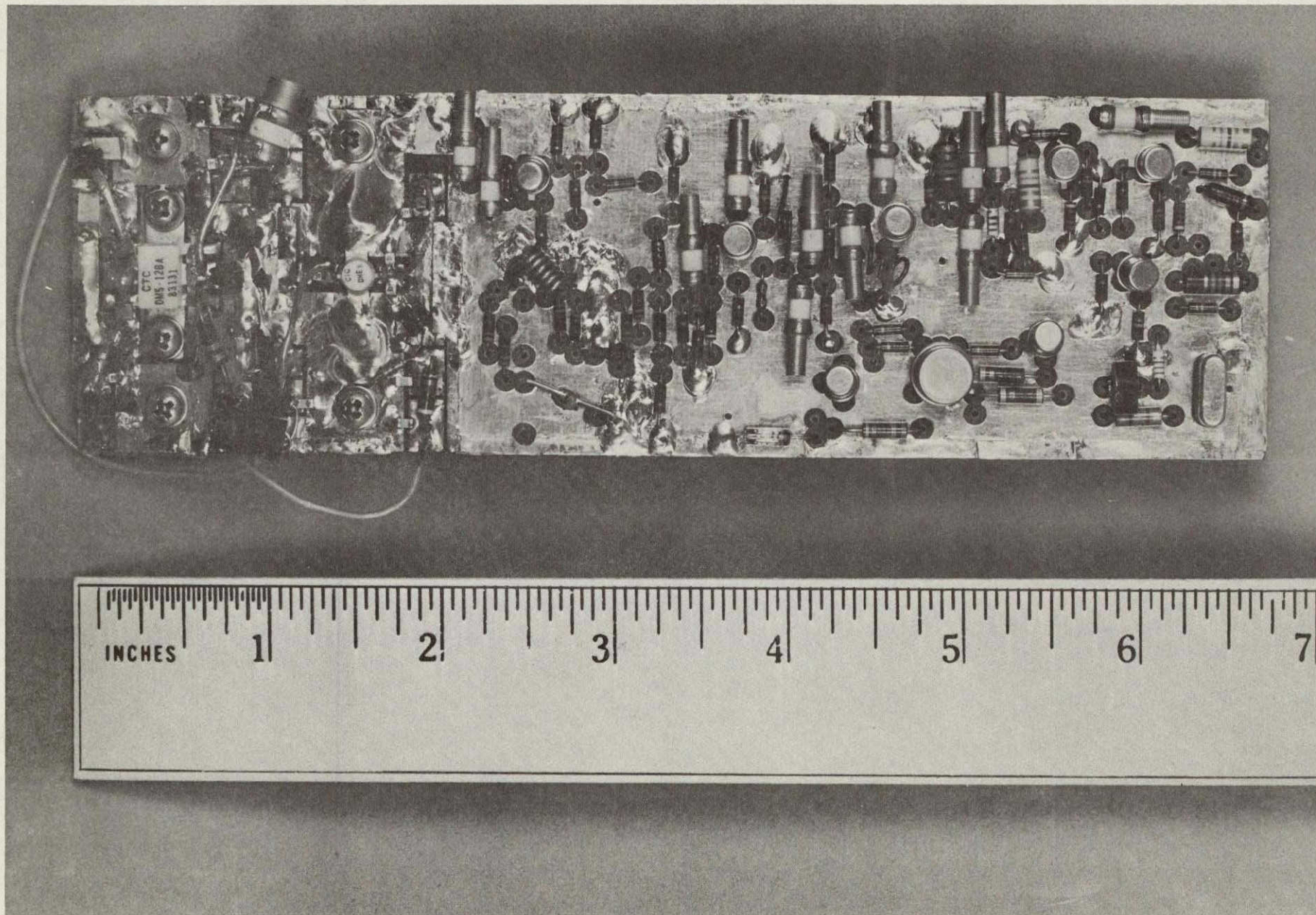
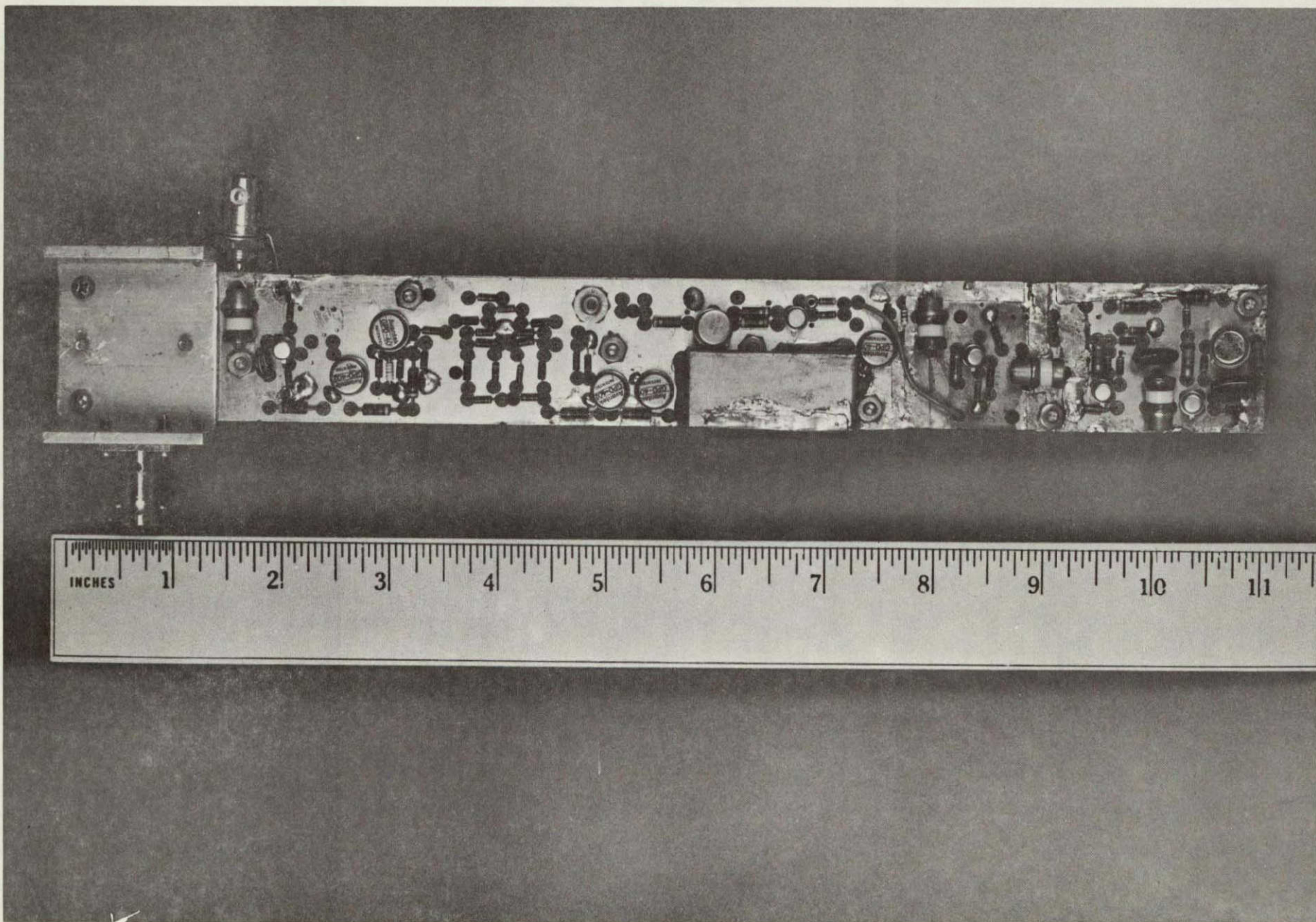


Figure 2-2. MDCP1



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Figure 2-3. MDCP2

TABLE 2-2

MDCP1 HIGHLIGHTS

Parameter	Design Goal	Achieved
Volume (CC)	400	369 ⁽¹⁾
Weight (GM)	300	375 ⁽¹⁾
System Efficiency (%) (MDCP1)	65	61
Short Term Frequency Stability (100 ms)	1×10^{-9}	0.9×10^{-10}
Frequency Temperature Coefficient - 40°C to +45°C (Parts Per Million)	± 5	± 3
Spurious Response (db below carrier)	25	42
Power Output Change (Ref 3W) -40°C to +45°C (db)	± 1	± 0.3
Modulation (Degrees)	$63.0^\circ \pm 5.7^\circ$	$63.0^\circ \pm 4^\circ$

⁽¹⁾The weight and volume of the unit includes the battery power supply. The weight and volume are directly related to the system lifetime and therefore directly impacts the number of batteries required. The figures shown are for 6 months operation, transmission interval of 40 sec, transmit time of 390 millisecond and operation for 3 hours out of each 24 hrs. The batteries assumed were four Mallory LO27 Lithium Sulphur Dioxide cells.

SECTION 3

SYSTEM BUILDING BLOCKS

A typical block diagram of a MDCP system is shown in figure 2.1. Each section of the system will be analyzed in detail but particular attention will be directed at the stable oscillator and output power amplifier. The oscillator and amplifier represent areas where the greatest contribution to cost, size, and efficiency can be made.

3.1 THE OSCILLATOR

Two 50.2 MHz oscillators were considered during the program: an integrated oscillator and an oscillator consisting of discrete components.

3.1.1 Integrated Oscillator

Figure 3-1 is a schematic diagram of the integrated oscillator test circuit. The oscillator is manufactured by Plessey Semiconductors and is representative of these type oscillators. The oscillator is packaged in a standard TO-5 can and costs less than five dollars in small quantities. The low cost and small size of the oscillator make it very attractive for use in the Miniature DCP. However, tests on the oscillator brought two major deficiencies to light. First, the unit tested requires 6.8 milli-ampere at 6 volts. A design goal for the system oscillator current was established as 1 mA. Second, the oscillator does not track the crystal $\Delta f/f$ over temperature. Figure 3-2 shows data on two crystals which were measured in the test oscillator and in the Hewlett-Packard Vector Impedance Meter.

3.1.2 Discrete Component Oscillator

Figure 3-3 is a schematic diagram of the discrete component oscillator and the transistor equivalent circuit used in the analysis of the oscillator. In the oscillator schematic R_4 and C_3 form a power supply decoupling network, C_4 bypasses R. F. signals at the emitter of Q_1 , R_1 and R_2 provide bias to transistor Q_1 , and C_5 is a D. C. blocking capacitor. Figure 3-3C shows the R. F. equivalent circuit of the oscillator. The transfer function from base to collector of the transistor can be written from Figure 3-3C as:

$$\frac{V}{V_C} = H(j\omega_0) = \frac{\frac{1}{j\omega_0 C_1}}{R + j\omega_0 L_1 + \frac{1}{j\omega_0 C_1}}$$

where R is the crystal impedance at its series resonant frequency (ω_0). The impedance (Z) seen looking into the equivalent circuit (Figure 3-3C) from the collector is

$$Z(j\omega_0) = \frac{\left(\frac{1}{j\omega_0 C_2} \right) \left(R + j\omega_0 L_1 + \frac{1}{j\omega_0 C_1} \right)}{R + j\omega_0 L_1 + \frac{1}{j\omega_0 C_2} + \frac{1}{j\omega_0 C_1}}$$

Now, a gain (A) can be defined as

$$A = \frac{V_C}{V} = gmZ(j\omega_0)$$

Using the equation for A and the equation for H ($j\omega_0$), the circuit of Figure 3-3C can be represented as shown in Figure 3-4.

The Barkhausen criterion for oscillation [5] requires that

$$AH(j\omega_0) \geq 1$$

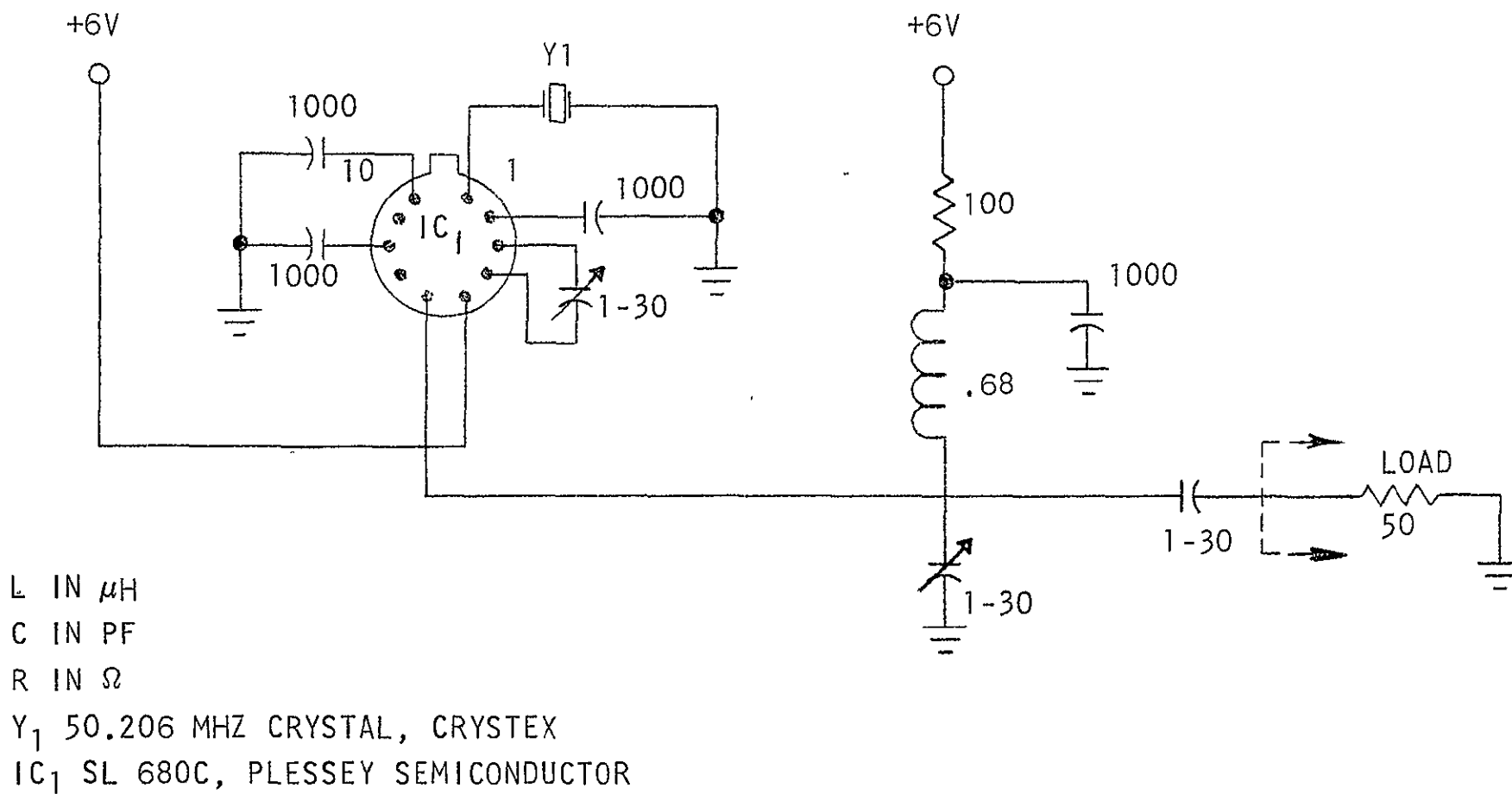


Figure 3-1. Integrated Oscillator

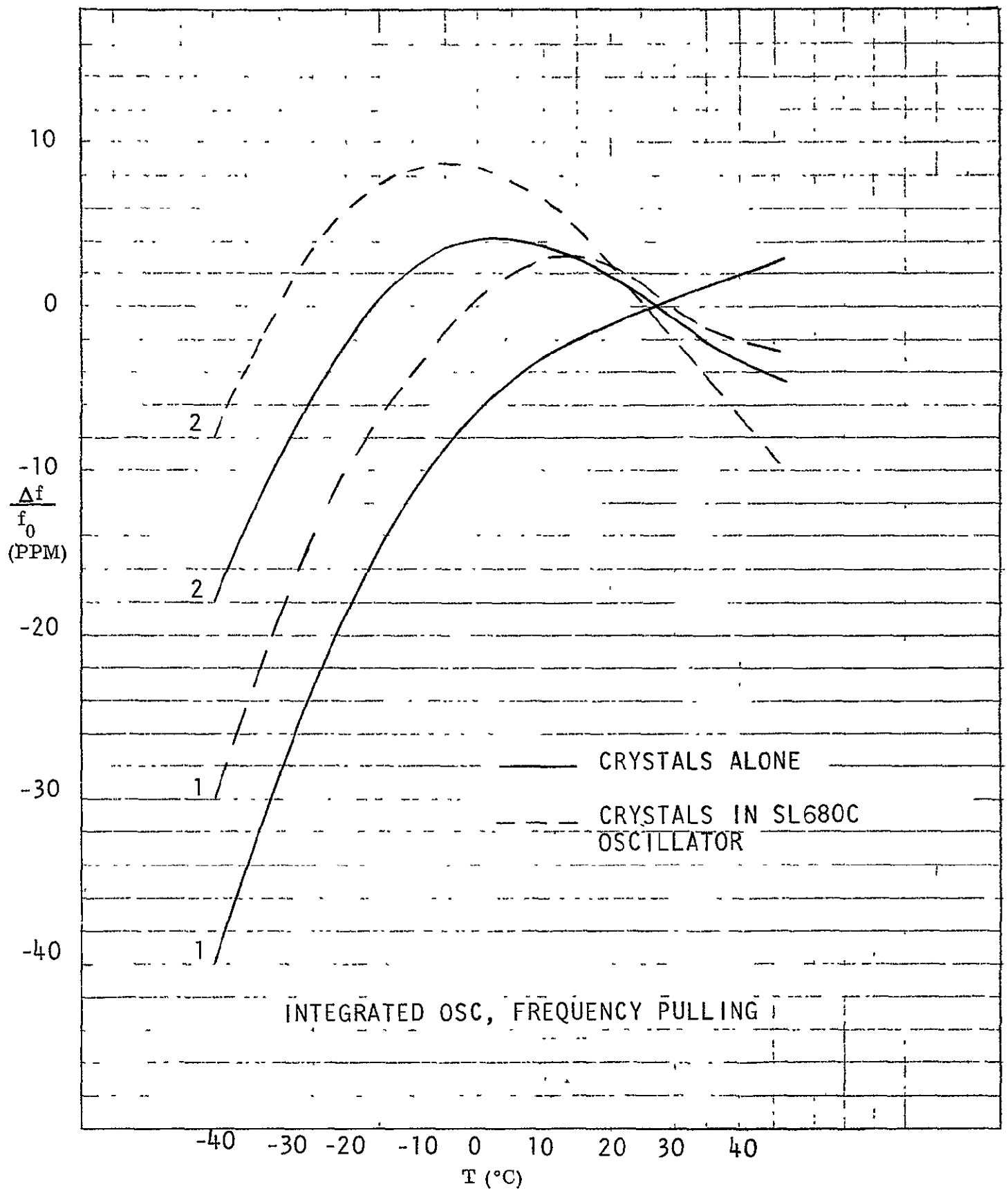
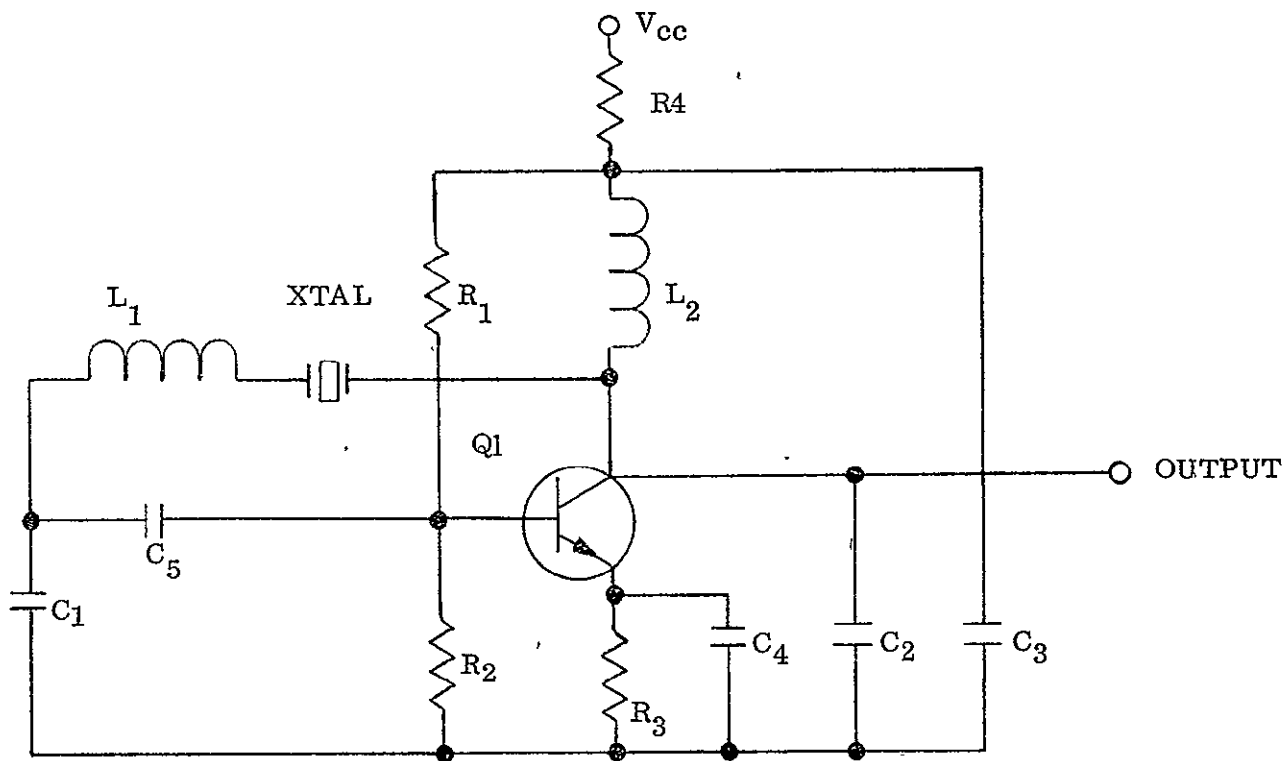
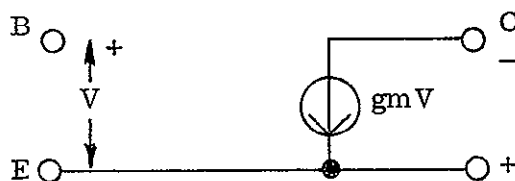


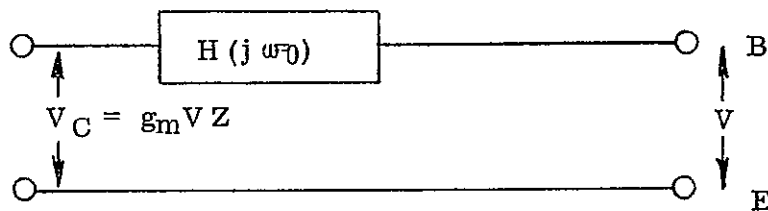
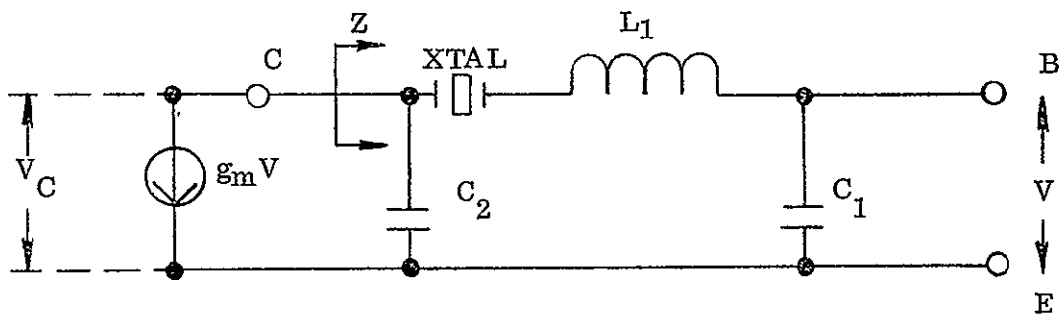
Figure 3-2. Integrated OSC, Frequency Pulling



A. OSCILLATOR SCHEMATIC

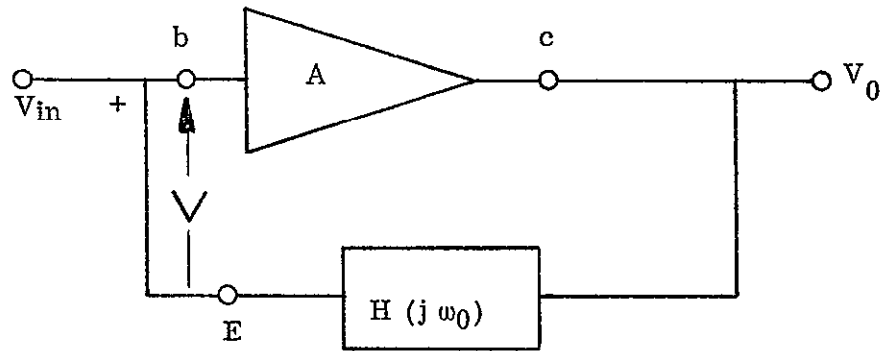


B. SIMPLIFIED HYBRID- π TRANSISTOR EQUIVALENT CIRCUIT ([4] CHAPTER 3)



C. EQUIVALENT CIRCUIT APPLIED TO THE OSCILLATOR

Figure 3-3.



$$A = \frac{-g_m \left(\frac{1}{j\omega_0 C_2} \right) \left(R + j\omega_0 L + \frac{1}{j\omega_0 C_1} \right)}{R + j\omega_0 L + \frac{1}{j\omega_0 C_1} + \frac{1}{j\omega_0 C_2}} = -g_m Z(j\omega_0)$$

$$H(j\omega_0) = \frac{\frac{1}{j\omega_0 C_1}}{R + j\omega_0 L + \frac{1}{j\omega_0 C_1}}$$

Figure 3-4. The Oscillator as a Feedback System

or

$$\frac{\frac{g_m}{\omega_0^2 C_1 C_2}}{R + j\omega_0 L + \frac{1}{j\omega_0 C_1} + \frac{1}{j\omega_0 C_2}} \geq 1$$

$$\frac{\frac{g_m}{\omega_0^2 C_1 C_2}}{R + j\omega_0 L + \frac{1}{j\omega_0 C_P}} \geq 1 \quad \text{where: } C_P = \frac{C_1 C_2}{C_1 + C_2}$$

$$\frac{g_m}{\omega_0^2 C_1 C_2} - R - j\omega_0 L - \frac{1}{j\omega_0 C_P} \geq 0$$

This last equation requires that

$$j\omega_0 L_1 = -\frac{1}{j\omega_0 C_P} \quad \text{or} \quad \omega_0 = \frac{1}{\sqrt{L_1 C_P}}$$

and

$$\frac{g_m}{\omega_0^2 C_1 C_2} \geq R \quad \text{or} \quad g_m \geq R \omega_0^2 C_1 C_2$$

The equation

$$\omega_0 = \frac{1}{\sqrt{L_1 C_P}}$$

determines the value of $L_1 C_P$ in terms of ω_0 , the crystal frequency.

The equation

$$g_m \geq R \omega_0^2 C_1 C_2$$

determines the value of g_m required for oscillation. The parameter g_m can be expressed in terms of the transistor emitter current as

$$g_m = \frac{q |I_e|}{kT}$$

where T is the temperature in degrees Kelvin : $^{\circ}\text{C} + 273.18$

k is Boltzman's constant : 1.38×10^{-23} Joule/ $^{\circ}\text{K}$

q is the charge on an electron : 1.6×10^{-19} Coulomb

Therefore,

$$\frac{q |I_e|}{kT} \geq R \omega_0^2 C_1 C_2$$

$$|I_e| \geq R \omega_0^2 C_1 C_2 \left(\frac{kT}{q} \right)$$

is a condition on I_e which insures oscillation.

Since current in a battery operated system is important, the last equation puts a lower limit on the oscillator current required in the system. The following paragraphs will develop the minimum current required for such systems.

It is shown in section 3.3.3 that the crystal compensation technique inserts a maximum resistance of $1 \times 1/2$ ohms in series with the crystal. Table 3-2 of section 3.3.4 shows that $1 \times 1 \geq 400$. Therefore, the maximum value of resistance inserted in series with the crystal by the compensation technique is 200 Ohms.

Figure 3-5 shows the oscillator constructed for testing. Q_1 forms the oscillator while Q_2 and Q_3 are buffer/amplifiers. The amplifier formed by Q_3 saturates on its input signal and, therefore, provides a constant power output over temperature. The value of C_2 used in the oscillator is 33 Pf, L_2 is $0.47 \mu H$. At 50 MHz these values in parallel result in an equivalent capacity of 58 Pf. Therefore, $C_2 = 58 \text{ Pf}$.

The emitter current I_e required to sustain oscillations can be calculated as

$$I_e \geq R \omega_0^2 C_1 C_2 \left(\frac{kT}{q} \right)$$

The worst case value of R is 200Ω ; at room temperature ($290^\circ K$)

$$\frac{kT}{q} = 25.7 \times 10^{-3} \text{ volt.}$$

$$I_e \geq (200) (2\pi \times 50 \times 10^6)^2 (27 \times 10^{-12}) (58 \times 10^{-12}) (25.7 \times 10^{-3})$$

$$I_e \geq 0.79 \text{ Milli-Ampere}$$

At $+45^\circ C$ $kT/q = 27.5 \times 10^{-3}$ and the required minimum emitter current is 0.85 Milli-Amperê.

A current (I_e) of one milli-Ampere was used as I_e for Q_1 in the circuit of Figure 3-5.

Table 3-1 shows the operation of the circuit of Figure 3-5 over temperature. The fact that the circuit does operate from $-40^\circ C$ to $+40^\circ C$ indicates that currents of approximately one milli-Ampere are adequate for the oscillator. Table 3-1 also shows the saturation characteristics of Q_3 . Figure 3-6 shows a comparison of the $\Delta f/f$ of the crystal oscillator, and the crystal alone (measured with a Hewlett-Packard 4815A Vector Impedance Meter).

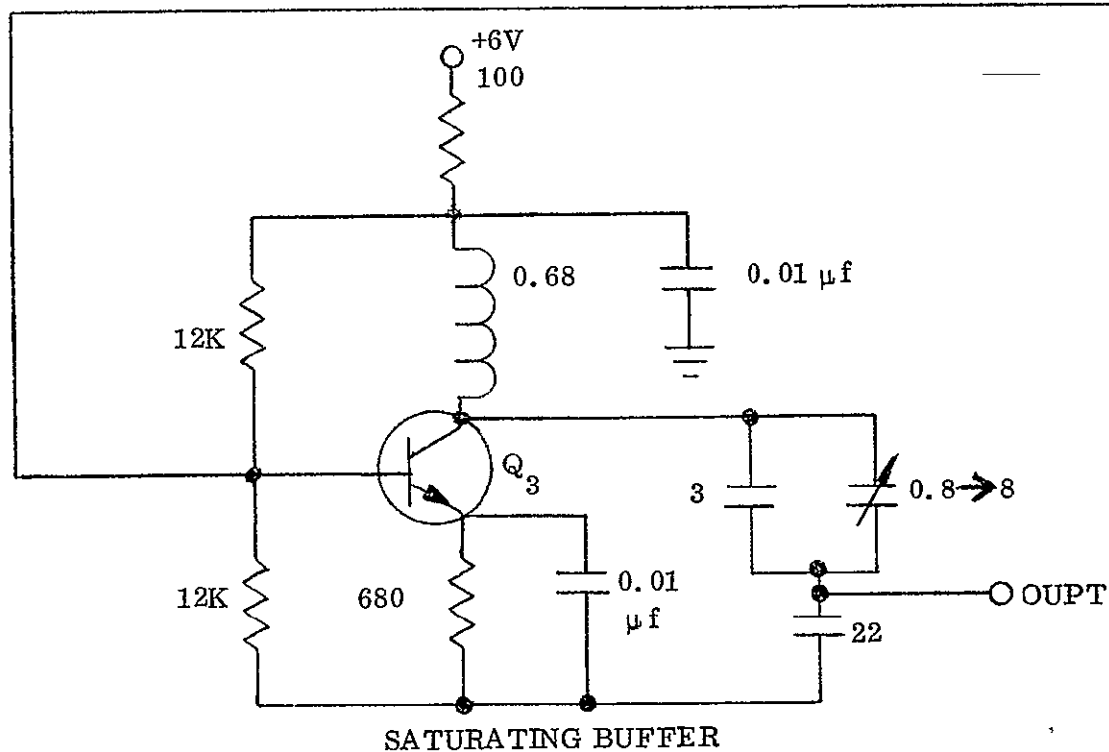
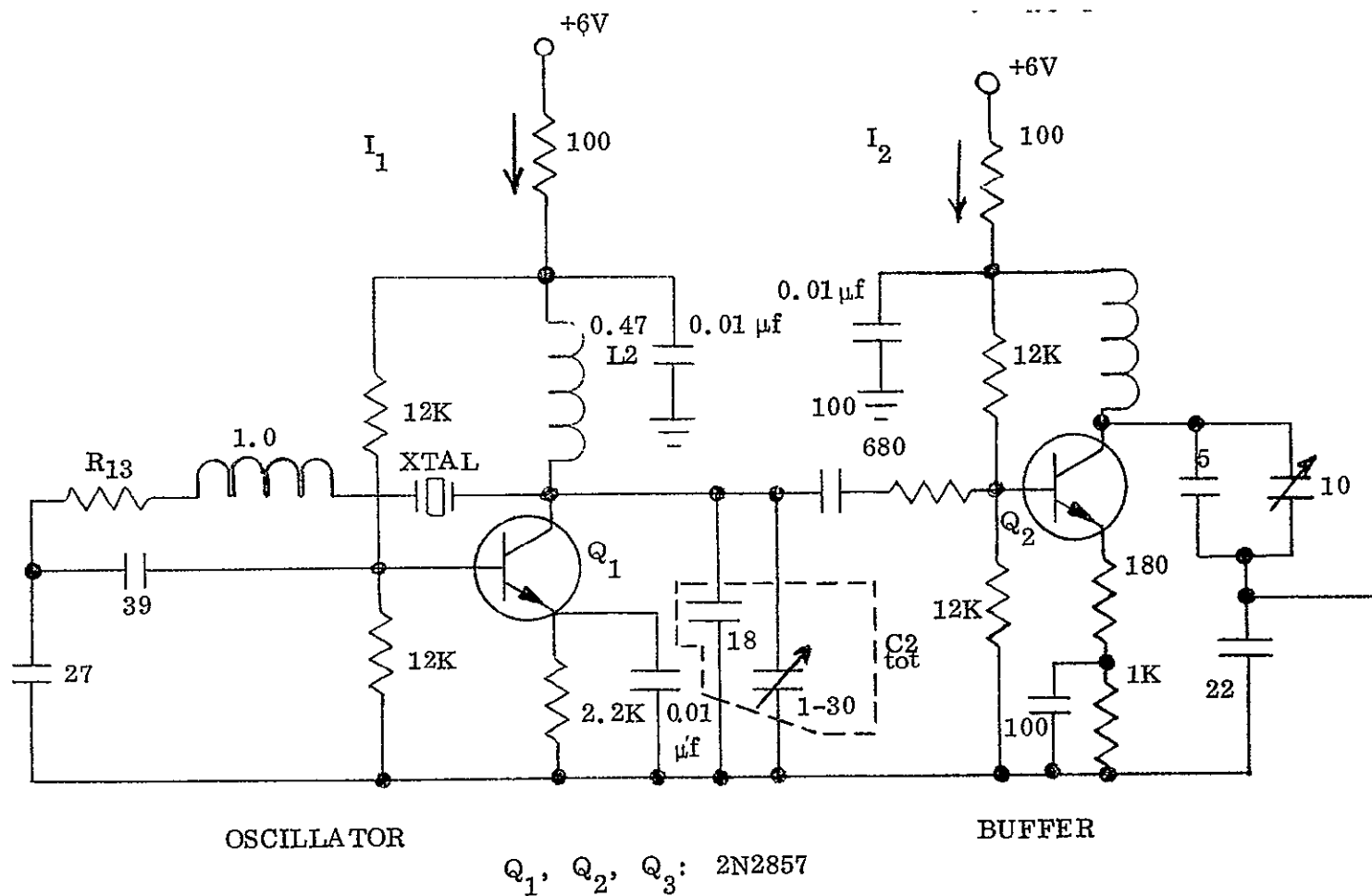


Figure 3-5. Schematic Diagram Crystal Oscillator/Buffer

Table 3-1. Saturation Characteristics

<u>T (°C)</u>	<u>Po (mW)</u>	<u>Po (Milliwatt)</u>
	Qz	Q3
	<u>R13 = 200 Ω</u>	5.0
-40	.19	5.0
-30	.195	5.0
-20	.20	5.0
-10	.205	5.0
0	.21	5.0
10	.21	4.9
20	.205	4.8
30	.20	4.7
40	.195	4.7
	<u>R13 = 100 Ω</u>	5.3
-40	.45	5.2
-30	.47	5.2
-20	.49	4.6
-10	.50	4.5
0	.50	4.5
10	.51	4.5
20	.51	4.6
30	.51	4.6
40	.50	
	<u>R13 = 27 Ω</u>	5.4
-40	1.2	5.4
-30	1.3	5.4
-20	1.3	5.4
-10	1.35	5.2
0	1.4	5.4
10	1.4	5.2
20	1.4	5.2
30	1.4	5.1
40	1.4	

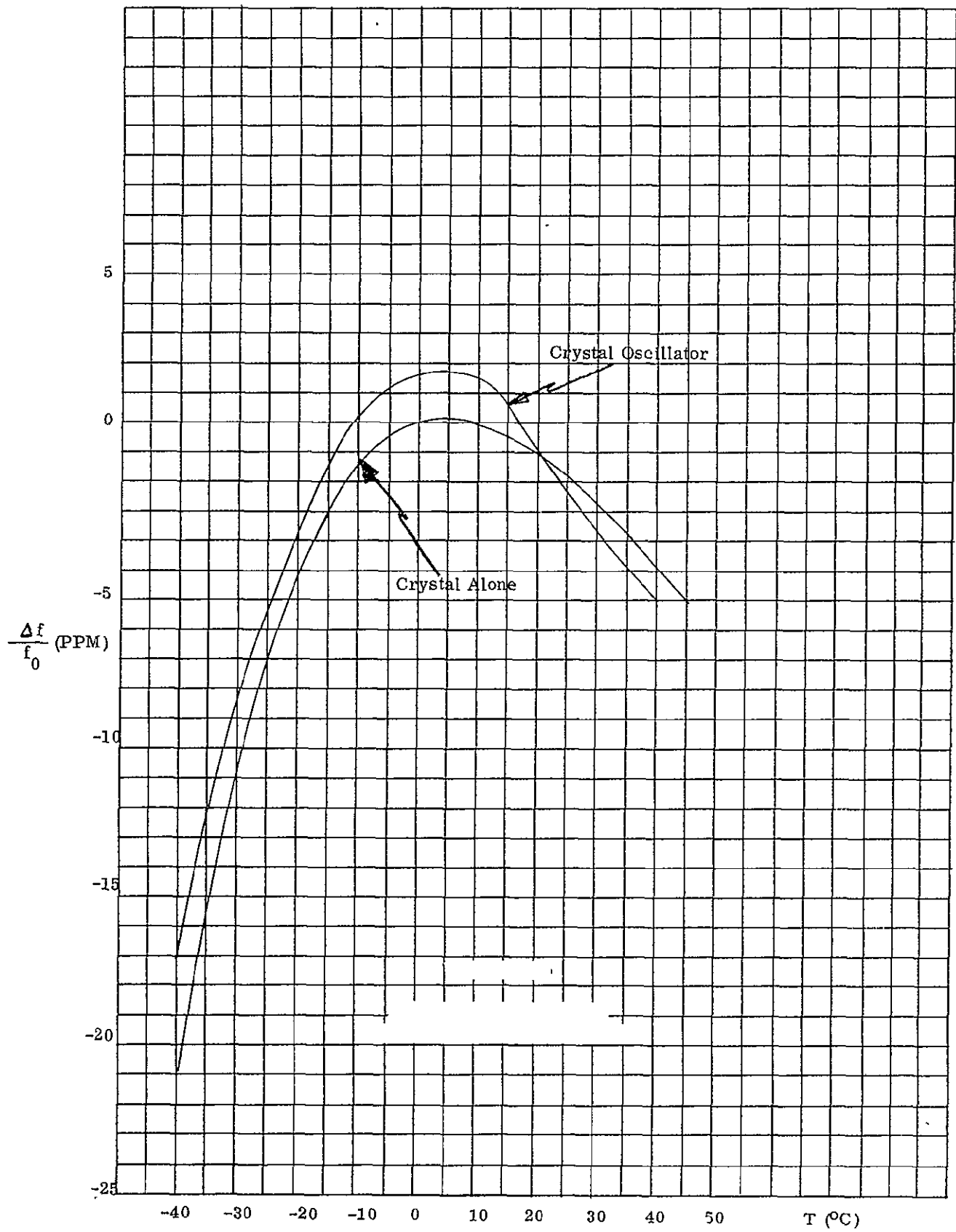


Figure 3-6. Oscillator/Crystal Temp. vs Freq. Tracking

3.2 CRYSTAL TEMPERATURE COMPENSATION TECHNIQUE

Since the Miniature Data Collection Platform (MDCP) is battery operated it must operate at low current levels if the MDCP size & weight requirements are to be met. The MDCP is also required to have a frequency stability greater than the native stability of an uncompensated crystal. These three requirements, battery operation, frequency stability & small size, require that the MDCP employ a low current drain temperature vs frequency compensation network. The above requirements obviously exclude the use of an oven.

This section describes a simple, passive (low power drain) oscillator temperature compensation technique. This technique (first reported in [2], [3]) consists of placing of a temperature varying reactance in series with the oscillator crystal. The compensation network consists of a thermistor in parallel with a capacitive reactance. The thermistor and capacitor are chosen so that the reactance of the network tracks the crystal and compensates it over temperature.

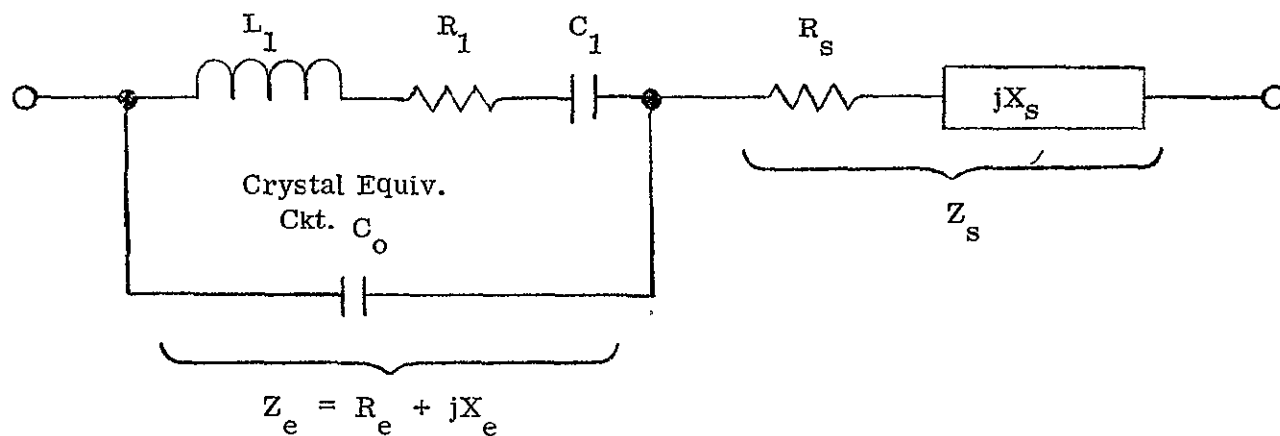
In application, the compensation network is chosen by superimposing the original $\Delta f/f$ curve of the crystal on a family/curves representing the composite $\Delta f/f$ due to the compensation network. A compensation curve which most closely matches the crystal is chosen for compensation.

The compensation technique is designed to operate over the range of -40°C to $+45^{\circ}\text{C}$. Advantages of the technique are that it is simple and does not require repeated temperature testing of the crystal and compensation network. As a consequence the technique is inexpensive to apply. Secondly, the technique is passive in that it does not require battery power and therefore results in a low-power drain oscillator. This technique provides compensation to approximately ± 5 PPM (Parts Per Million) in the temperature range -40°C to $+45^{\circ}\text{C}$.

3.3 CRYSTAL CHARACTERIZATION -- TERMINAL IMPEDANCE

Notation and terminology for a crystal equivalent circuit and an added series impedance is given in Figure 3-7. The terminal impedance (Z_e) of the crystal can be derived from Figure 3-7 as follows:

$$Z_e = \frac{(R_1 + jX_1) jX_0}{R_1 + j(X_1 + X_0)}$$



Let $X_1 = \omega L_1 - \frac{1}{\omega C_1}$ and $X_0 = \frac{-1}{\omega C_0}$; $r = \frac{C_0}{C_1}$

and ω denotes radian frequency

then with this definition established, the above diagram reduces to

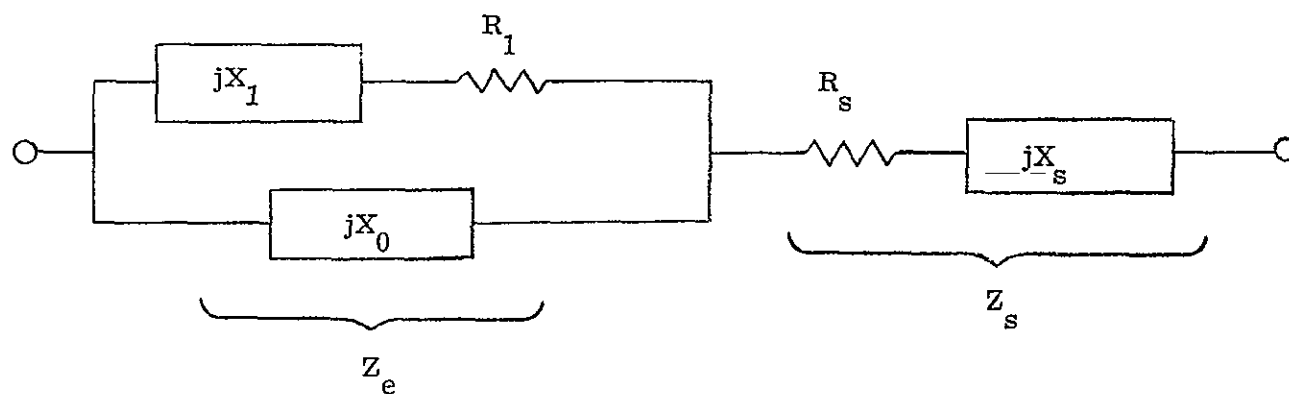


Figure 3-7.

Crystal Equivalent Circuits and Terminology

Rationalizing and collecting real and imaginary terms yields

$$\begin{aligned}
 Z_e &= \frac{R_1^2 X_0^2}{R_1^2 + (X_1 + X_0)^2} + j \frac{R_1^2 X_0 + X_1 X_0 (X_1 + X_0)}{R_1^2 + (X_1 + X_0)^2} \\
 &= R_e + j X_e
 \end{aligned}
 \tag{1}$$

3.3.1 CRYSTAL SERIES REACTANCE (X_e)

An expression for crystal series reactance is developed in this section.

$$\begin{aligned}
 X_e &= \frac{R_1^2 X_0 + X_1 X_0 (X_1 + X_0)}{R_1^2 + (X_1 + X_0)^2} \\
 &= \frac{\frac{R_1^2 X_0}{(X_1 + X_0)} + X_1 X_0}{\frac{R_1^2}{X_1 + X_0} + X_1 + X_0} = \frac{\frac{R_1^2}{X_1 + X_0} + X_1}{\frac{R_1^2}{X_0 (X_1 + X_0)} + 1 + \frac{X_1}{X_0}}
 \end{aligned}$$

Assume

$$\frac{R_1^2}{X_1 + X_0} + X_1 \approx X_1 \text{ and therefore } \frac{R_1^2}{X_0 (X_1 + X_0)} + \frac{X_1}{X_0} \approx \frac{X_1}{X_0}$$

(The symbol $\approx$ denotes "approximately equal to")

then,

$$X_e \approx \frac{X_1}{1 + \frac{X_1}{X_0}}
 \tag{2}$$

A useful approximation for X_1 will now be derived.

$$X_1 = \omega L_1 - \frac{1}{\omega C_1}$$

$$\text{Let } \omega_s \triangleq \frac{1}{\sqrt{L_1 C_1}}$$

(The symbol $\triangleq$ denotes "defined as"). That is, ω_s is the resonant frequency of the series elements R_1 , C_1 , L_1 of Figure 3-1.

$$X_1 = \left(\frac{\omega}{\omega_s}\right) \omega_s L_1 - \left(\frac{\omega_s}{\omega}\right) \frac{1}{\omega_s C_1}$$

Substituting $\frac{1}{\omega_s C_1} = \omega_s L_1$ yields

$$X_1 = \omega_s L_1 \left(\frac{\omega}{\omega_s} - \frac{\omega_s}{\omega} \right)$$

Now, let

$$S \triangleq \frac{\omega - \omega_s}{\omega_s} \quad \text{then}$$

$$1 + S = 1 + \frac{\omega - \omega_s}{\omega_s} = \frac{\omega}{\omega_s} \quad \text{and}$$

$$\frac{\omega}{\omega_s} - \frac{\omega_s}{\omega} = 1 + S - \frac{1}{1 + S} = \frac{S(2 + S)}{1 + S}$$

If ω is restricted to frequencies near ω_s then $|S| \ll 1$ and

$$\frac{\omega}{\omega_s} - \frac{\omega_s}{\omega} \approx 2S = 2\left(\frac{\omega - \omega_s}{\omega_s}\right)$$

X_1 can now be written as

$$X_1 \approx 2 L_1 (\omega - \omega_s) \text{ for } \left| \frac{\omega - \omega_s}{\omega_s} \right| \ll 1 \quad (3)$$

Using the relationship $\omega_s = \frac{1}{\sqrt{L_1 C_1}}$ Equation (3) can be written as

$$X_1 \approx \frac{2 \Delta \omega}{\omega_s^2 C_1} = \frac{2 \frac{\Delta \omega}{\omega_s}}{\omega_s C_1 \left(\frac{C_0}{C_1} \right)} = \frac{2 \frac{\Delta f}{f_s} r}{\omega_s C_0}$$

where: $r \triangleq \frac{C_0}{C_1}$

Let $X_0 \triangleq \frac{-1}{\omega_s C_0}$ then

$$X_1 \approx -2X_0 r \frac{\Delta f}{f_s} \text{ for } \left| \frac{\omega - \omega_s}{\omega_s} \right| \ll 1 \quad (3a)$$

The derivation of an expression for X_e continues below.

Substituting equation (3) into equation (2) yields

$$X_e \approx \frac{2L_1 \Delta \omega}{1 + \frac{2L_1 \Delta \omega}{X_0}} \text{ where } \Delta \omega \triangleq \omega - \omega_s \quad (4)$$

Substituting equation (3a) into equation (2) yields

$$X_e \approx \frac{-2 X_0 r \frac{\Delta f}{f_s}}{1 - 2 r \frac{\Delta f}{f_s}} \quad (4a)$$

where $\Delta f = f - f_s$ and $2\pi f = \omega$

Equations (4) and (4a) were derived using the approximation $\left| \frac{\omega - \omega_s}{\omega_s} \right| = \left| \frac{\Delta f}{f_s} \right| \ll 1$.

In the following analysis, only values of $\left| \frac{\Delta f}{f_s} \right| < 100$ PPM (Parts Per Million) will be considered. Therefore, the approximation is justified.

3.3.2 SERIES REACTANCE ($X_s + X_e$) AND TEMPERATURE COMPENSATION

The compensation technique consists of adding a reactance (X_s) in series with the crystal to "retune" the crystal. The frequency of interest is the frequency for which $Z_s + Z_e$ is real. That is, the frequency for which $X_s + X_e = 0$. Let ω_o denote the required frequency. Then $X_s + X_e = 0$ for $\omega = \omega_o$, and

$$X_s = \frac{2 X_o \frac{\Delta f_o}{f_s} r}{1 - 2 \frac{\Delta f_o}{f_s} r} = 0$$

$$X_s = \frac{2 X_o \frac{\Delta f_o}{f_s} r}{1 - 2 \frac{\Delta f_o}{f_s} r} \quad (5)$$

Where: $\Delta f_o = f_o - f_s$ and $2\pi f_o = \omega_o$ is the frequency for which $X_s + X_e = 0$

Rearranging equation (5) yields

$$\frac{\Delta f_o}{f_s} = \frac{X_s}{2 r (X_s + X_o)} \quad (6)$$

Equation (6) can be interpreted as follows. The change in crystal $\frac{\Delta f_o}{f}$ may be positive or negative. In the following, this change in $\frac{\Delta f_o}{f}$ with temperature is called crystal drift. If positive, then the $\frac{\Delta f_o}{f}$ provided by equation (6) must be negative in order to compensate the crystal. If the crystal drift is in the negative direction, X_s must be chosen so that the $\frac{\Delta f_o}{f}$ of equation (6) is positive. Therefore, since $X_o \gg X_s$ and X_o is always negative, a negative X_s (capacitive) will provide a positive $\frac{\Delta f_o}{f}$ and cancel a negative $\frac{\Delta f_o}{f}$ crystal drift. Similarly, a positive X_s (inductive) will cancel a positive crystal drift.

3.3.3 THE COMPENSATING NETWORK

Figure 3-8 shows the compensating network to be added in series with the crystal. R_T represents the resistance of the thermistor. The impedance Z_t is derived as follows:

$$Z_t = \frac{j X R_T}{R_T + j X}$$

Rationalizing and collecting terms yields

$$Z_t = \frac{\frac{X^2}{R_T}}{1 + \frac{X^2}{R_T^2}} + j \frac{X}{1 + \frac{X^2}{R_T^2}} \quad (7)$$

$$Z_t = R_t + j X_t$$

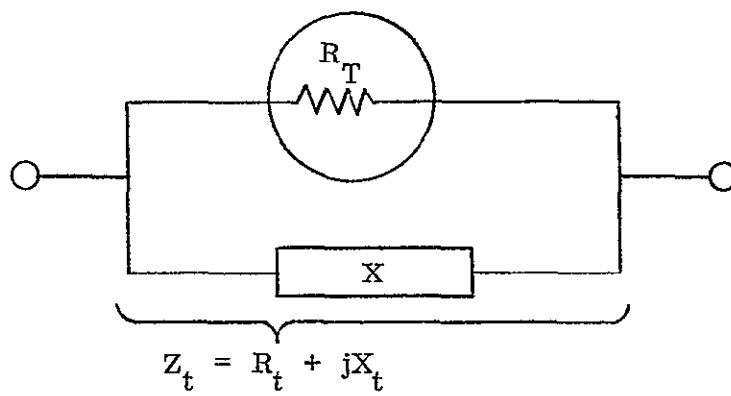


Figure 3-8. Thermistor/Reactance Compensation Network

Since R_t appears in series with the crystal and varies with temperature, the maximum value $\overline{(R_t)}$ of R_t is of interest.

Differentiating the real part of eqn (7) and equating to zero yields:

$$\frac{d R_t}{d R_T} = \frac{R_T^2}{R_T^2 + X^2} \left(- \frac{X^2}{R_T^2} \right) - \frac{\frac{X^2}{R_T^2} (-2) \frac{X^2}{R_T^3}}{\frac{R_T^2 + X^2}{R_T^2}}$$

$$\frac{d R_t}{d R_T} = \frac{-X^2}{R_T^2 + X^2} + \frac{2 X^4}{(R_T^2 + X^2)^2} = 0$$

$$-1 + \frac{2 X^2}{R_T^2 + X^2} = 0 \quad (8)$$

$$2 X^2 = R_T^2 + X^2$$

$$R_T = X$$

Consider $\frac{d R_t}{d R_T}$,

$$\frac{d R_t}{d R_T} = \frac{-X^2}{R_T^2 + X^2} + \frac{2 X^4}{(R_T^2 + X^2)^2} = \frac{X^2}{R_T^2 + X^2} \left(\frac{2 X^2}{R_T^2 + X^2} - 1 \right)$$

The term $\frac{2X^2}{R_T^2 + X^2} - 1$ is greater than zero for $R_T < X$, equals zero for $R_T = X$

and is less than zero for $R_T > X$. Therefore, $X = R_T$ is a maximum for R_t .

Substituting $X = R_T$ into the real part of Eq. 7 yields the maximum value of R_t .

$$\overline{R}_t = \frac{\frac{X^2}{\overline{X}}}{1 + \frac{X^2}{\overline{X}^2}} = \frac{X}{2} \quad (9)$$

3.3.4 COMPENSATION TECHNIQUE

Figures 3-9A and 3-9B are plots of equation (6), with X_s of equation (6) taken equal to X_t of equation (7)*. The curves are plotted for the values of X and R_{25} given in Table 3-2. Curves in Figure 3-9 were plotted for the family of thermistors shown in Appendix IV and the curves in Figure 3-8 were inverted to show negative $\frac{\Delta f}{f}$ values. The actual calculated values are positive. These particular values of X and R_{25} were chosen to provide compensation for "AT" cut crystals in the range of cuts from 0' ~ 10' are shown in Figure 3-10. Figure 3-10 is adapted from Reference [1].

Since the curves of Figure 3-9 are inverted, Figures 3-9 and 3-10 can be superimposed over each other to choose a compensating curve for a particular crystal cut. Alternately, the $\Delta f/f_s$ variation of a crystal can be plotted on Figure 3-9 and the curve best fitting the crystal characteristics can be chosen to compensate the crystal.

*Details of the calculations are given in the Appendix I.

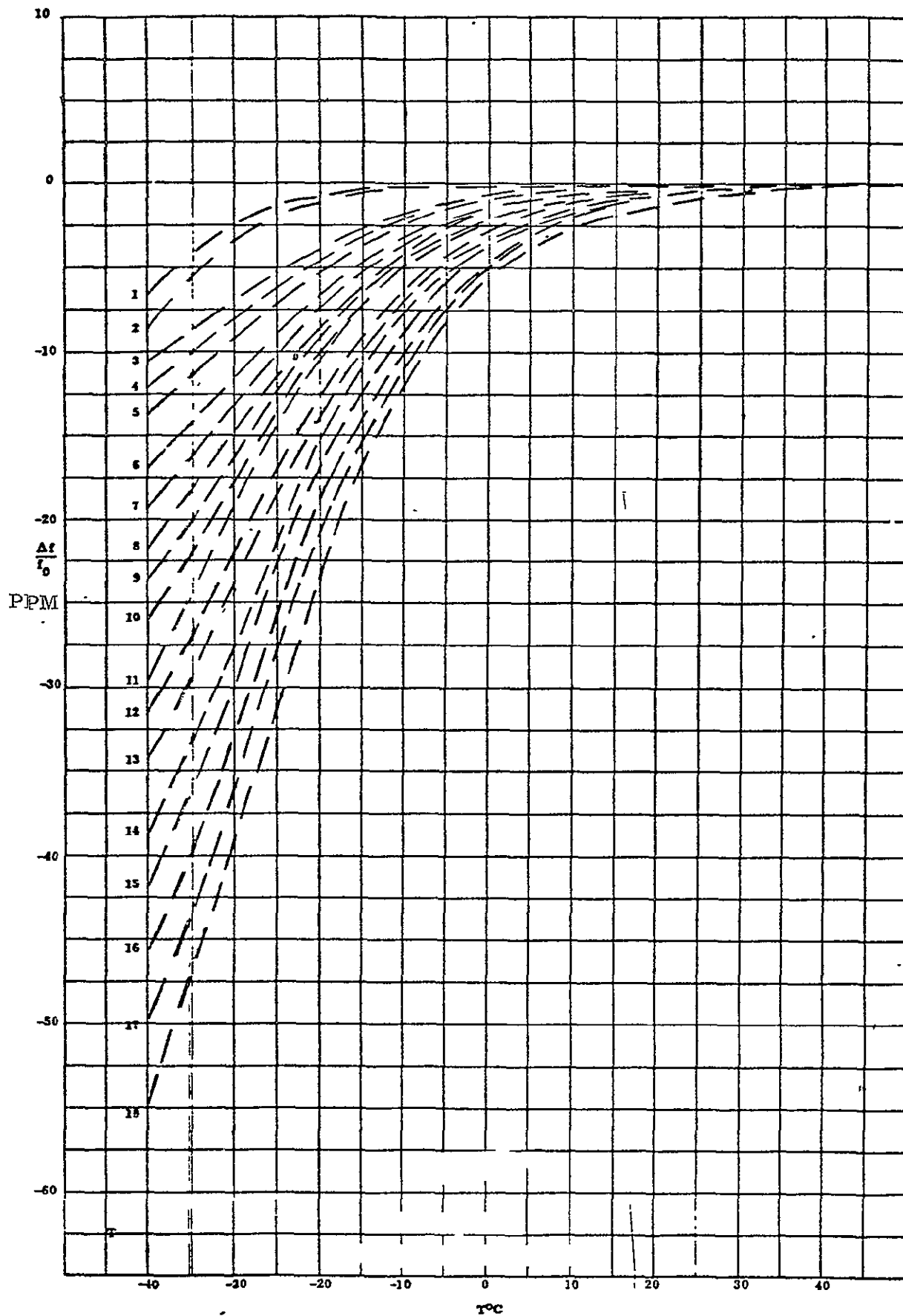


Figure 3-9A. Compensation Curve

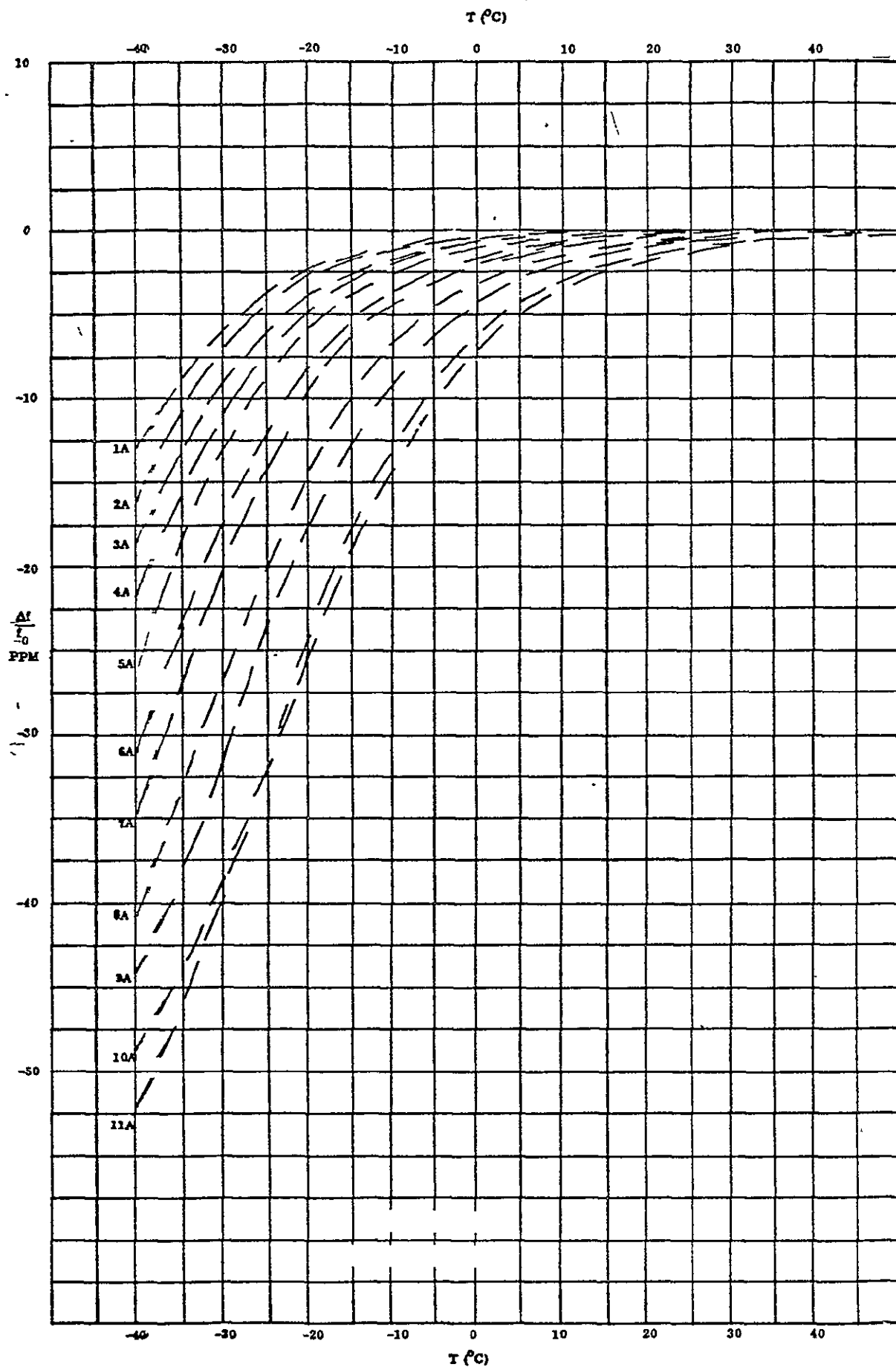


Figure 3-9B. Compensation Curves

TABLE 3-2

COMPONENT VALUES FOR COMPENSATION NETWORK

Curve No.	R_{25} (Ohm)	$-X$ (Ohm)
1A	7	150
2A	10	300
3A	10	200
4A	12	240
5A	14	288
6A	18	277
7A	19	274
8A	25	300
9A	30	300
10A	39	300
11A	39	300
1	6	340
2	6	240
3	6	60
4	7	70
5	8	80
6	10	100
7	11	114
8	13	130
9	14	144
10	16	160
11	18	200
12	19	190
13	22	220
14	25	254
15	28	280
16	32	320
17	35	350
18	39	394

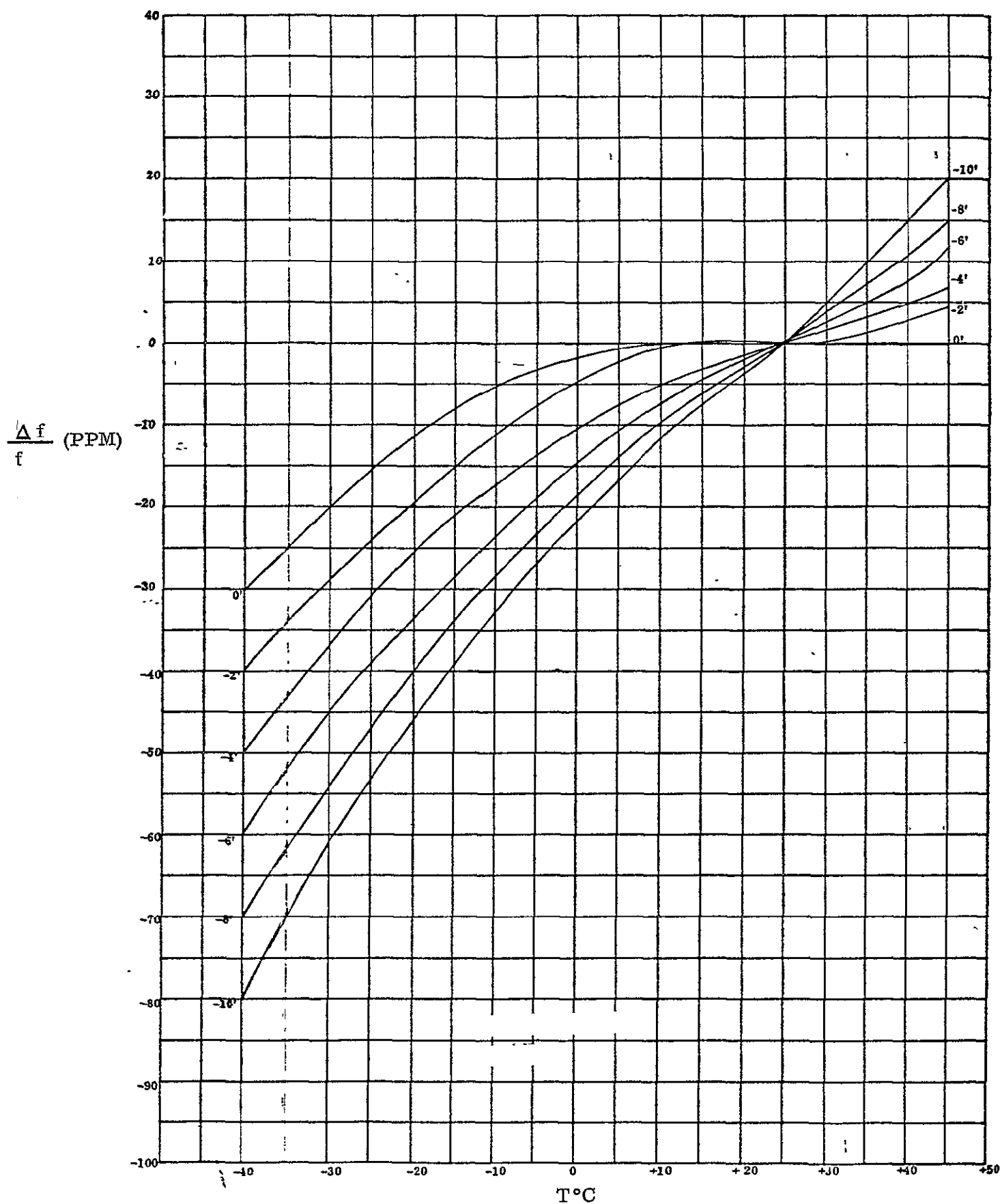


Figure 3-10. $\frac{\Delta f}{f}$; Crystal, "AT" Cut

Figure 3-11 shows the results of compensating 6 crystals. All were compensated as described previously. The crystal curves of $\Delta f/f$ vs. temperature were measured in a test oscillator. A compensation network was then chosen and the compensated oscillator was again tested over the same range of temperatures. The results of the compensated oscillator tests are given as numbered primed curves in Figure 3-11. In all six cases the compensated oscillators were well within ± 5 PPM frequency variation from -40°C to $+45^{\circ}\text{C}$.

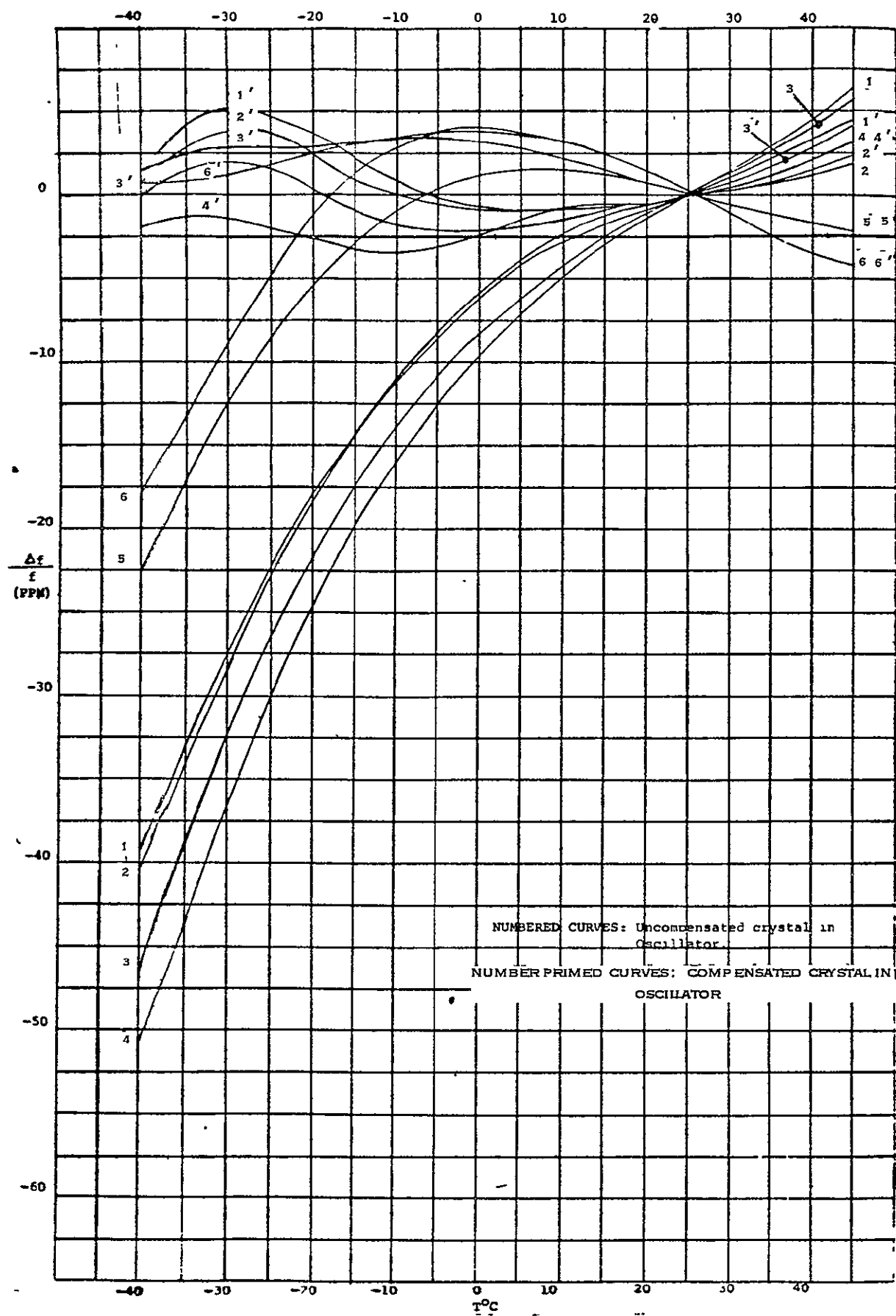


Figure 3-11.

3.3.5 PRACTICAL ASPECTS OF THE COMPENSATION TECHNIQUE

Appendix IV gives manufacturer's data on the thermistors used in the program. A plot (and a tabulation) of the D.C. value of R_T is given as part of this data. Also given is the theoretical relationship

$$R_T = R_{25} \text{ EXP } \left\{ B \left(\frac{1}{T} - \frac{1}{T_0} \right) \right\}$$

The manufacture's tabulated data and the theoretical relationship do not agree at lower temperatures. The reason for this disagreement in the manufacturers data is unknown. However, the theoretical relationship is true for all values when using data obtained in the AEL laboratory: Table 3-3 shows these values of R_T/R_{25} for various thermistors. Therefore, the theoretical relationship was used to calculate the compensation curves of Figure 3-9. Appendix I gives details on the calculation of the curves of Figure 3-9.

There are several sources of error in applying the compensation technique. One source of error is the tolerance on the C_0/C_1 ratio. Consider two crystals with identical C_0 but different C_0/C_1 ratios. From equation (6) the $\frac{\Delta f_0}{f_s}$ correction provided by a given series reactance X_s is

$$F_1 = \left. \frac{\Delta f_0}{f_s} \right|_1 = \frac{X_s}{2r_1(X_s + X_0)}$$

$$F_2 = \left. \frac{\Delta f_0}{f_s} \right|_2 = \frac{X_s}{2r_2(X_s + X_0)}$$

$$\frac{F_1}{F_2} = \frac{r_2}{r_1}$$

R_T/R_{25} From Cal-R Data Sheet (Appendix) III	Thermistor R_{25} (Specified) Ω R_{25} (Measured) Ω	1B18 50 60.5	1B22 30 39.4	1B26 10 11.4	1B28 5 7	1B33 2.5 3	1B117 75 89	1B119 15 19.3	1B147 60 70.7	1B225 20 25.4	Theoretical R_T/R_{25} *
45	.537	.525	.523	.543	.500		.522	.544	.523	.535	
35	.732	.719	.711	.702	.667	.667	.713	.710	.714	.701	
25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	1.18	1.20	1.21	1.26	1.17	1.33	1.19	1.18	1.19	1.21	1.18
10	1.68	1.74	1.76	1.84	1.77	1.67	1.73	1.71	1.72	1.76	1.7
0	2.45	2.57	2.72	2.75	2.63	2.67	2.55	2.51	2.54	2.69	2.5
-10	3.68	3.98	4.11	4.21	4.07	4.00	3.97	3.91	3.93	4.06	3.8
-20	5.69	6.12	6.45	6.82	6.43	6.27	6.09	6.17	6.11	6.43	5.9
-30	8.93	10.14	10.43	10.95	10.57	10.2	10.09	9.84	10.14	10.49	9.7
-40	14.4	16.67	16.65	17.46	16.83	16.33	16.59	15.8	16.65	16.6	16.5

*Computed from the eqn.

$$R_T/R_{25} = \text{EXP} \left\{ B \left(\frac{1}{T} - \frac{1}{T_0} \right) \right\}$$

(See Appendix IV)

Table 3-3. R_T/R_{25} Vs. Temperature

If r_1 is the correct ratio then the correction provided to crystal 2 by X_s is

$$F_2 = \frac{r_2}{r_1} F_1$$

Where F_1 is the expected compensation. Since the required compensation F_1 is larger the lower the temperature, the greatest error occurs at -40°C . (The lower limit of operating temperature for the system.) A second source of error is that the crystal frequency vs. temperature curve may not fall directly on one of the compensation curves of Figure 3-9. Here again the greatest error occurs at -40°C since the curves are most widely separated at this temperature. A third source of error is that the thermistors are not purely resistive at the lower temperatures. The reactive effect of the thermistors is most pronounced at -40°C . For instance, a 1B22 thermistor used in compensation network 10A has measured impedance

$$Z = 433 - j 193$$

at -40°C . In theory, the impedance at -40°C is

$$Z = 643.5 + j (0).$$

The impedance $Z = 433 - j193$ is equivalent to a parallel circuit of a resistor of 519 Ohms and a capacitive reactance of -1164. Ohms. Therefore, if the 1B22 were placed in parallel with a reactance of -300 Ohms (to yield compensation network 10A) the net reactance would consist of a 519 Ohm resistor in parallel with a reactance of -239 Ohm at -40°C . The result is that network 10A will undercompensate the crystal.

The three problems can be circumvented by running the oscillator or system over the temperature operation range after the compensation network is chosen. By using a variable reactance the compensation can be set exactly at the lower temperature extreme.

3.4 FREQUENCY MULTIPLIERS

Three types of frequency multipliers were considered during the program:

- Tuned Transistor Multipliers
- Cascaded (Not Tuned) Commercial Frequency Doublers
- Saturated Amplifier Multiplier

3.4.1 Tuned Transistor Frequency Multiplier

Figure 3-12 shows the X4 frequency multiplier (50 MHz to 200 MHz) and data on power gain. For testing purposes, a switch was used at the multiplier input. The switch, when in position 2 was used for measurement of input power (P_i) and in position 1 for measurement of output power (P_o). The data shows that the X4 multiplier output is saturated for input power between 1.5 to 5 Milli-Watt.

Figure 3-13 shows the X2 frequency multiplier (200 MHz to 400 MHz) and data on its power gain. Both the X2 and X4 frequency multipliers use tuned base, tuned collector configurations. The base tuning is not critical and the variable capacitors in the base circuits could be replaced with fixed capacitors. The data in figure 3-12 indicates that the X2 multiplier is useful over a large range of input power.

The oscillator/buffer and transistor frequency multiplier were connected as a system. Figure 3-14 is a block diagram of this system. The performance of the system over temperature is also tabulated in Figure 3-14. The total power variation of the system from -40°C to $+40^{\circ}\text{C}$ is 3.6 to 4.7 milliwatt. Figure 3-15 compares the frequency tracking vs temperature of the system and the crystal used in the system oscillator. As can be seen from Figure 3-15 the tracking is excellent. Figure 3-16 shows the output spectrum of the system.

3.4.2 Cascaded Commercial Frequency Doublers

Figure 3-17 shows a (X8) diode frequency multiplier. The amplifiers used (Avantek GPD402) are commercially available, broadband (5 - 400 MHz) and low cost in small quantities. The diode doubler used is also commercially available. The table below shows the response of a single amplifier/doubler combination at 50, 100 and 200 MHz input frequencies.

INPUT	INPUT	OUTPUT	OUTPUT
<u>FREQ (MHz)</u>	<u>POWER</u>	<u>FREQ (MHz)</u>	<u>POWER</u>
50	+7 dbm	100	-6 dbm
100	+7 dbm	200	-6 dbm
200	+7 dbm	400	-6 dbm

The minimum power gain of the amplifiers of Figure 3-17 is 13 db. Therefore, the amplifiers have sufficient gain to readjust the level at the output of each doubler to provide the appropriate drive for the succeeding doubler. Figure 3-18 shows the output spectrum of the diode X8 frequency multiplier.

3.4.3 Saturated Amplifier Multiplier

Figure 3-19 shows a Saturated Amplifier Multiplier. Amplifier U1 is saturated by the 50 MHz oscillator output producing a comb of frequencies at 50 MHz intervals. Filter F₁ selects out the 400 MHz component, which is amplified by U₂ and U₃.

Filter F₁ is a three-stage synchronously tuned filter centered at 400 MHz. The oscillator shown in Figure 3-19 is a modified version of the oscillator of Section 3.1.2. U₁ and U₂ are Avantek GPD401 Amplifiers. U₃ is an Avantek GPD402.

Figure 3-20 shows the signal spectra at various points in the multiplier. A -4 dbm 50 MHz input to U₁ yields a +2 dbm output at U₃.

3.4.4 Comparison of Transistor, Cascaded Frequency Doubler and Saturated Amplifier Multipliers

The following table compares the various multipliers:

	Cascaded Freq. <u>Doubler Mult.</u>	Transistor <u>Multiplier</u>	Saturated Amp. <u>Multiplier</u>
Current			
Required (mA)	80	10	45
Voltage Required			
(Volt)	15	6	15
Power Out at			
400 MHz			
(Milli-Watt)	4	6	1.5
Spurs (Ref.			
400 MHz Sig.			
as 0 db)	-12	-16	-30
Tuning	Not Req'd	Req'd	Req'd
			(Filter Only)

It is evident from the table above that for the multiplier's being compared the transistor multiplier requires the least current for its operation. For slightly higher currents the saturated amplifier multiplier is superior to the cascaded frequency doubler in almost all aspects. The small amount of tuning required by the saturated amplifier multiplier is more than outweighed by the higher parts count and larger currents required by the cascaded frequency doubler multiplier.

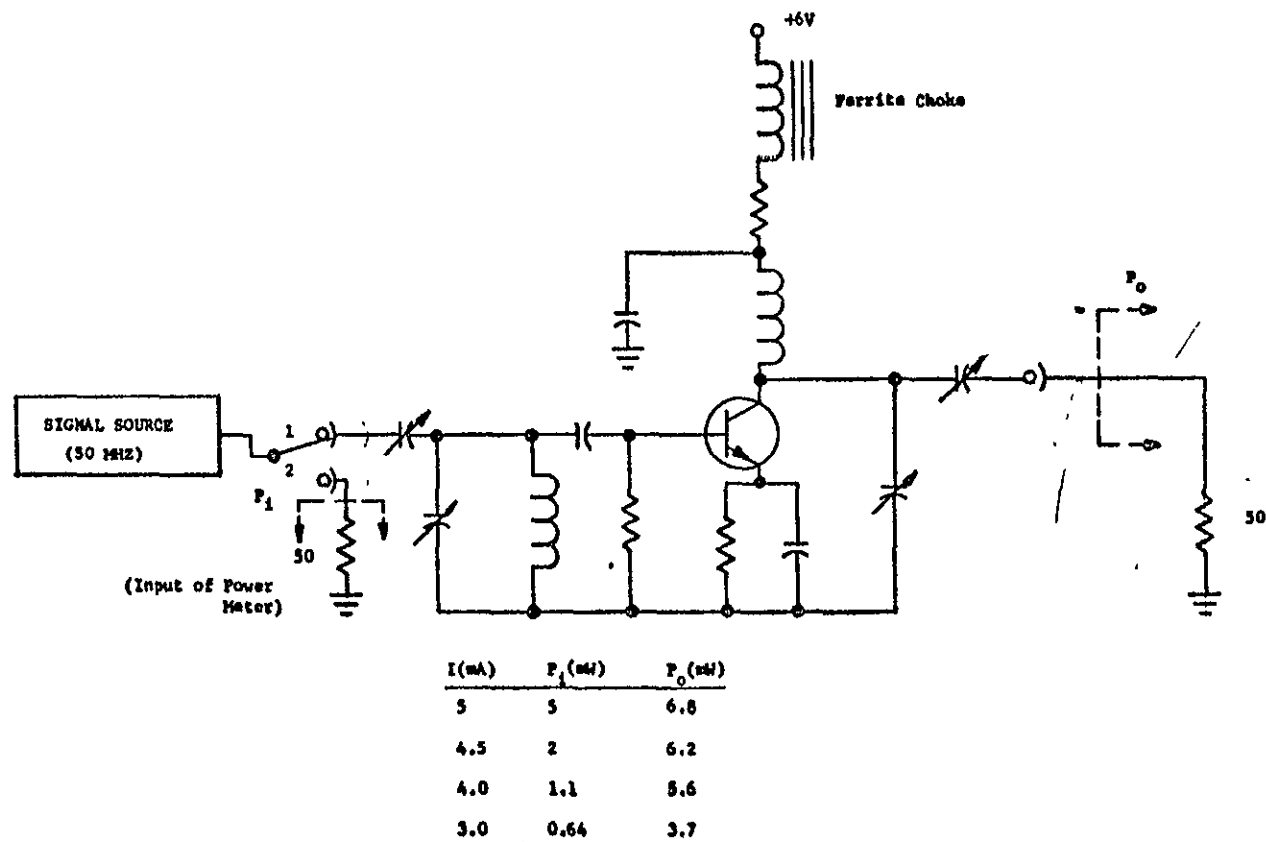


Figure 3-12. Amplifier-Quadrupler
(50 MHz to 200 MHz)

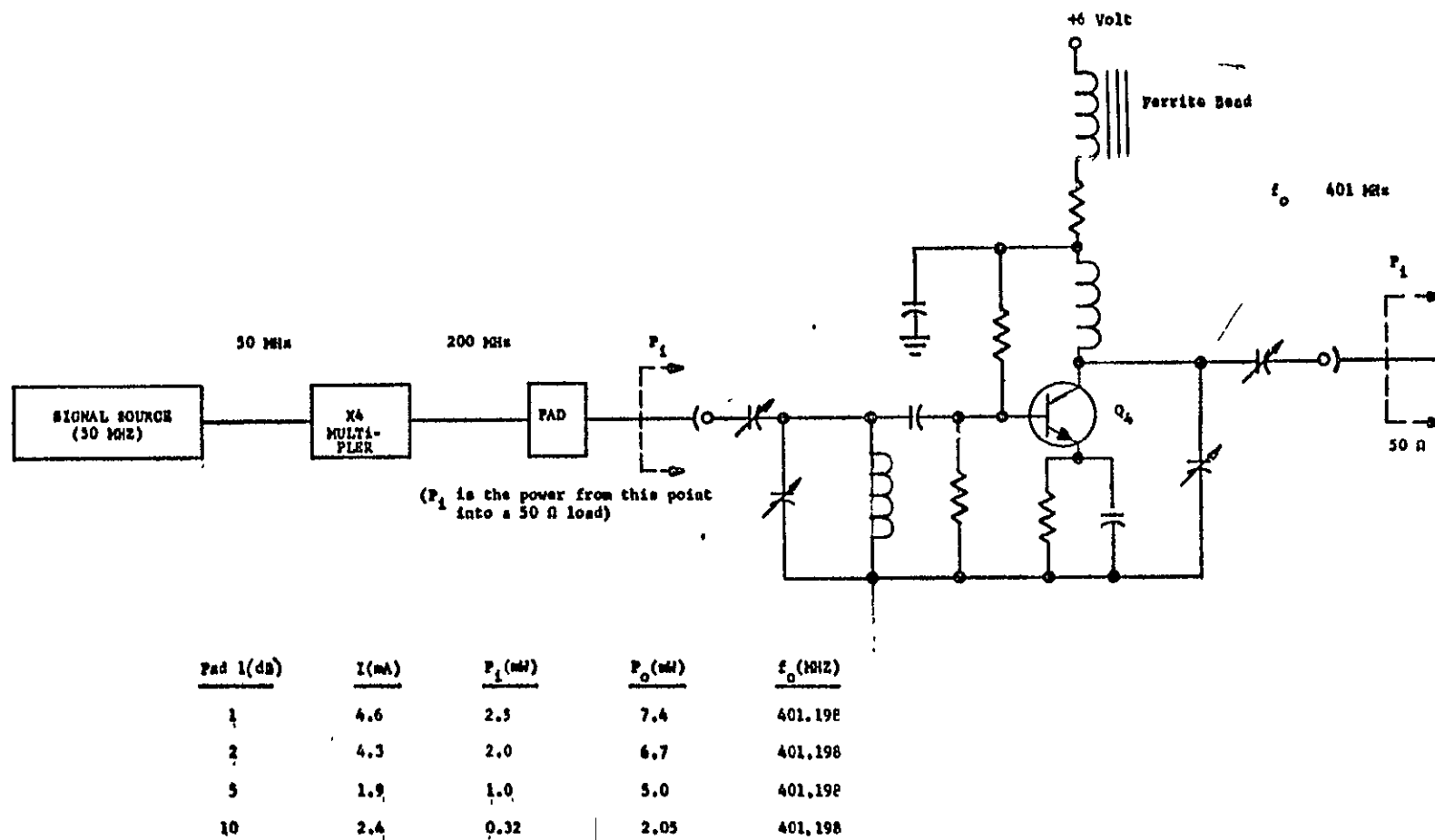
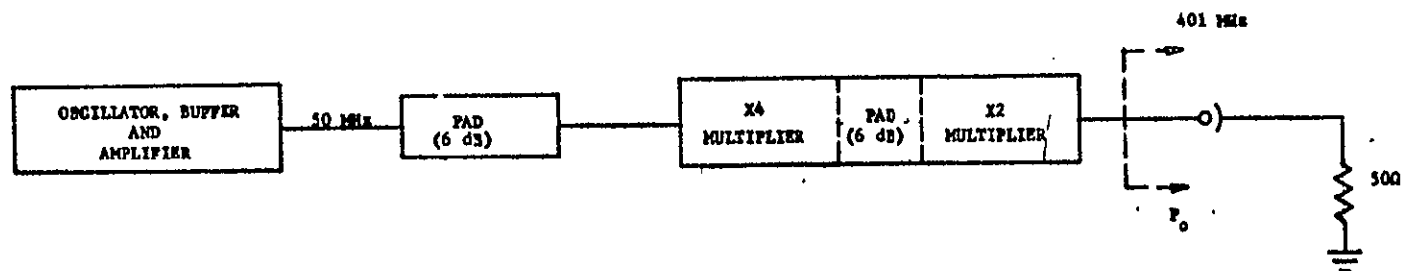


Figure 3-13. Amplifier-Doubler
(200 MHz - 400 MHz)



$T^{\circ}\text{C}$	$P_o(\text{mW})$
-40	3.6
-30	3.9
-20	4.2
-10	4.5
0	4.6
10	4.7
20	4.6
30	4.6
40	4.4

Figure 3-14. Oscillator/Multiplier System

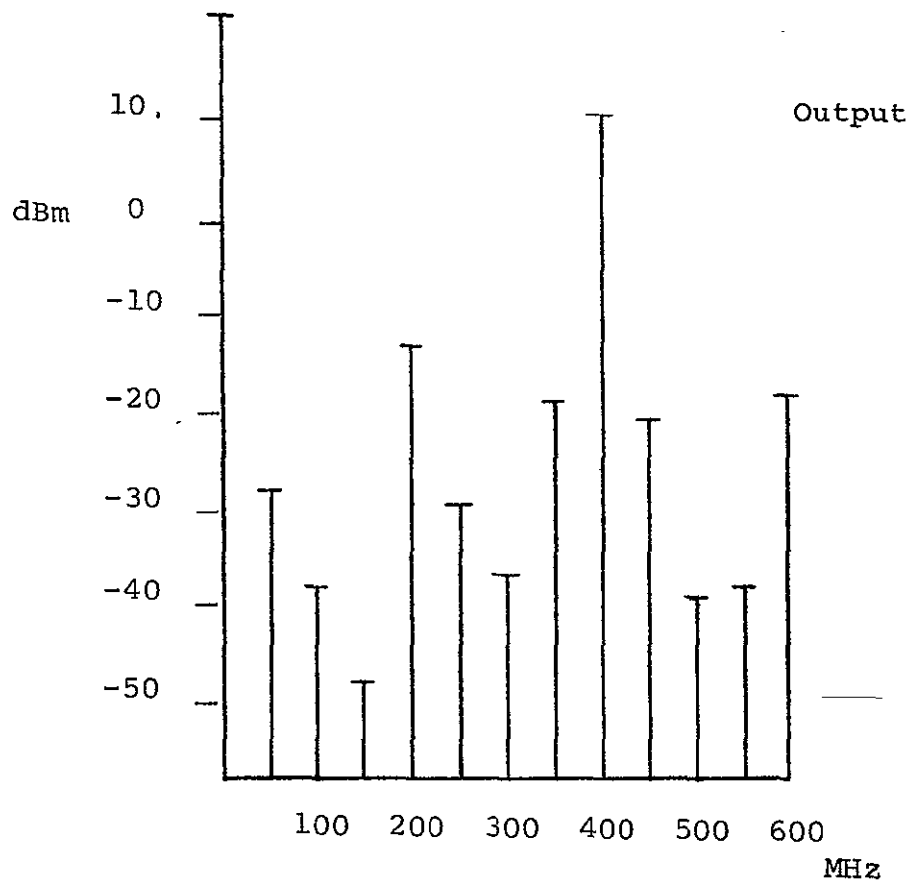
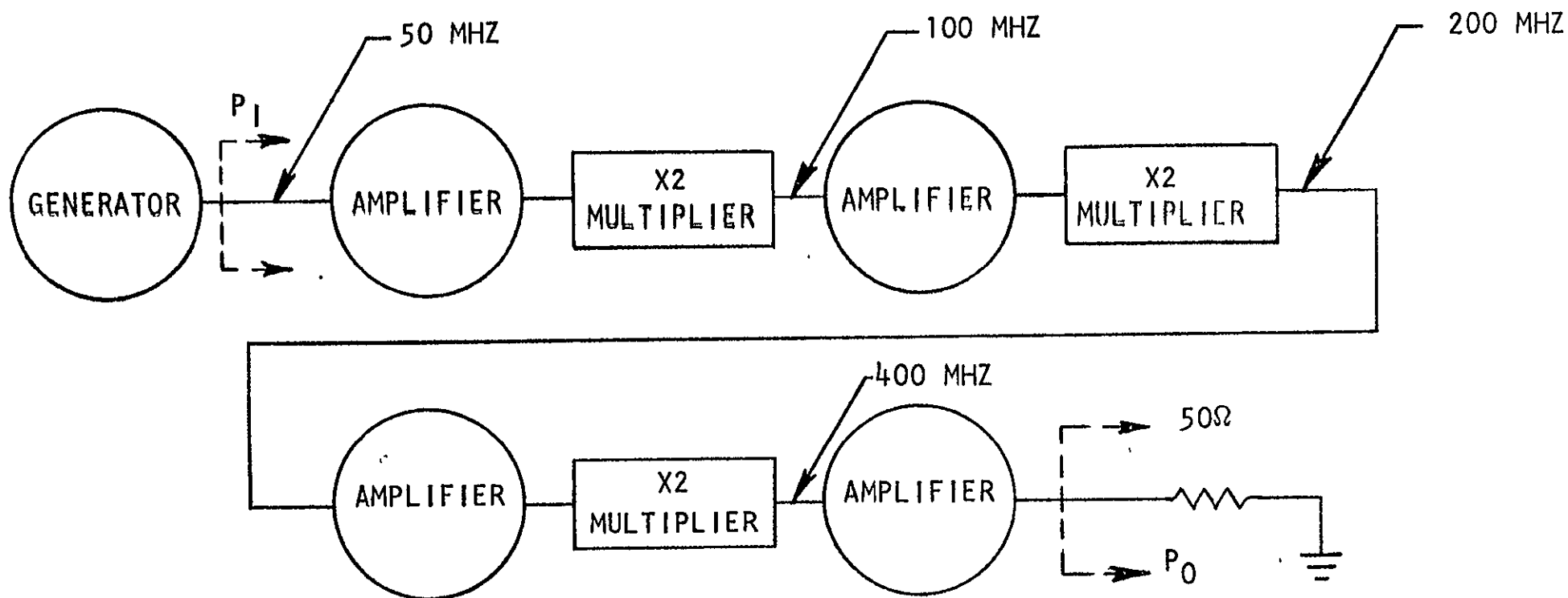


Figure 3-16. Oscillator/Multiplier System Output Spectrum



$P_1 = 8\text{MW}$
 $P_0 = 4\text{MW}$
 $I = 80\text{MA (TOTAL CURRENT)}$
 $V(\text{DC SUPPLY}) = 12\text{ VDC}$
 $F_{\text{OUT}} = 400\text{ MHz}$

Figure 3-17. Cascaded Frequency Doubler Multiplier
(50 MHz - 400 MHz)

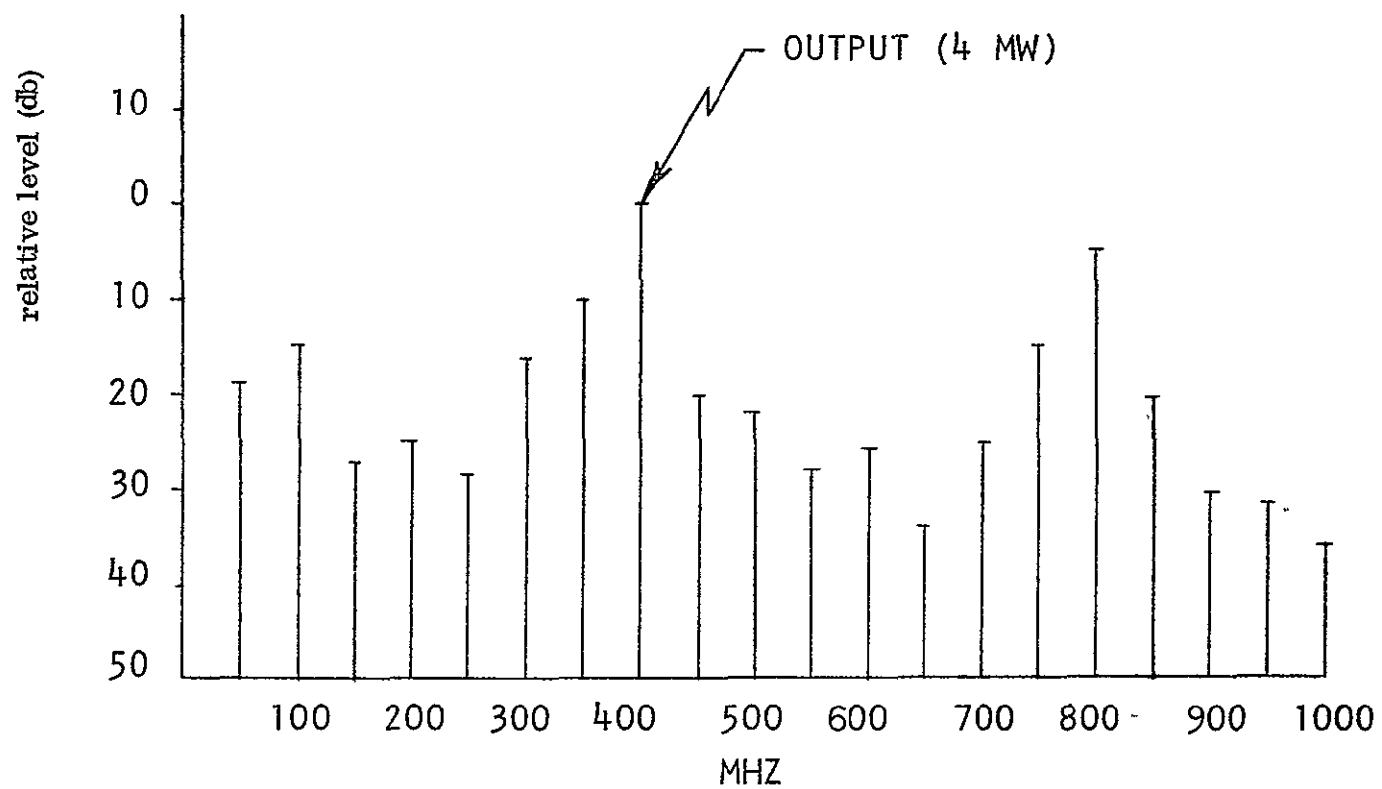


Figure 3-18. Multiplier Spectrum

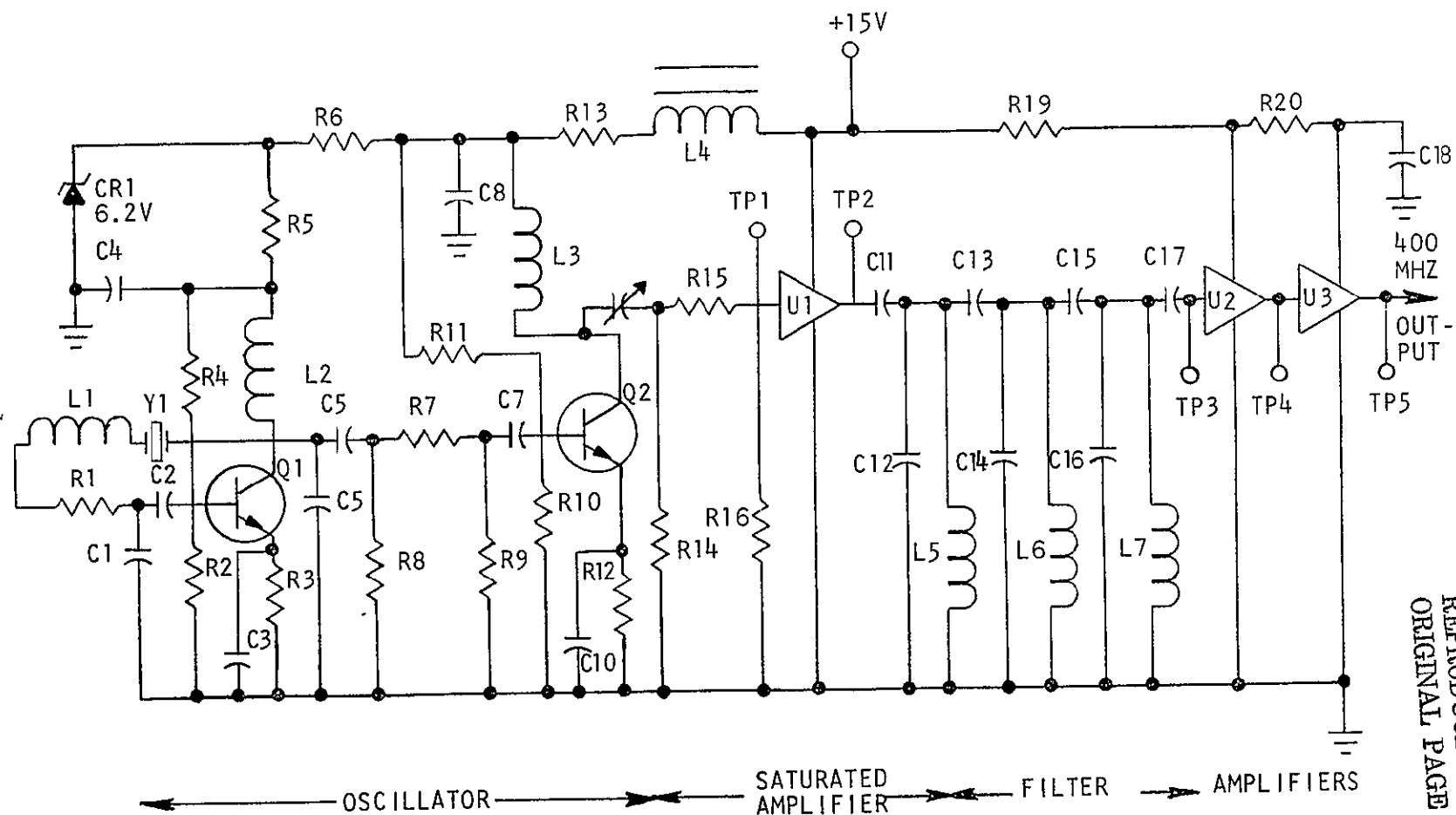


Figure 3-19. Saturated Amplifier Multiplier

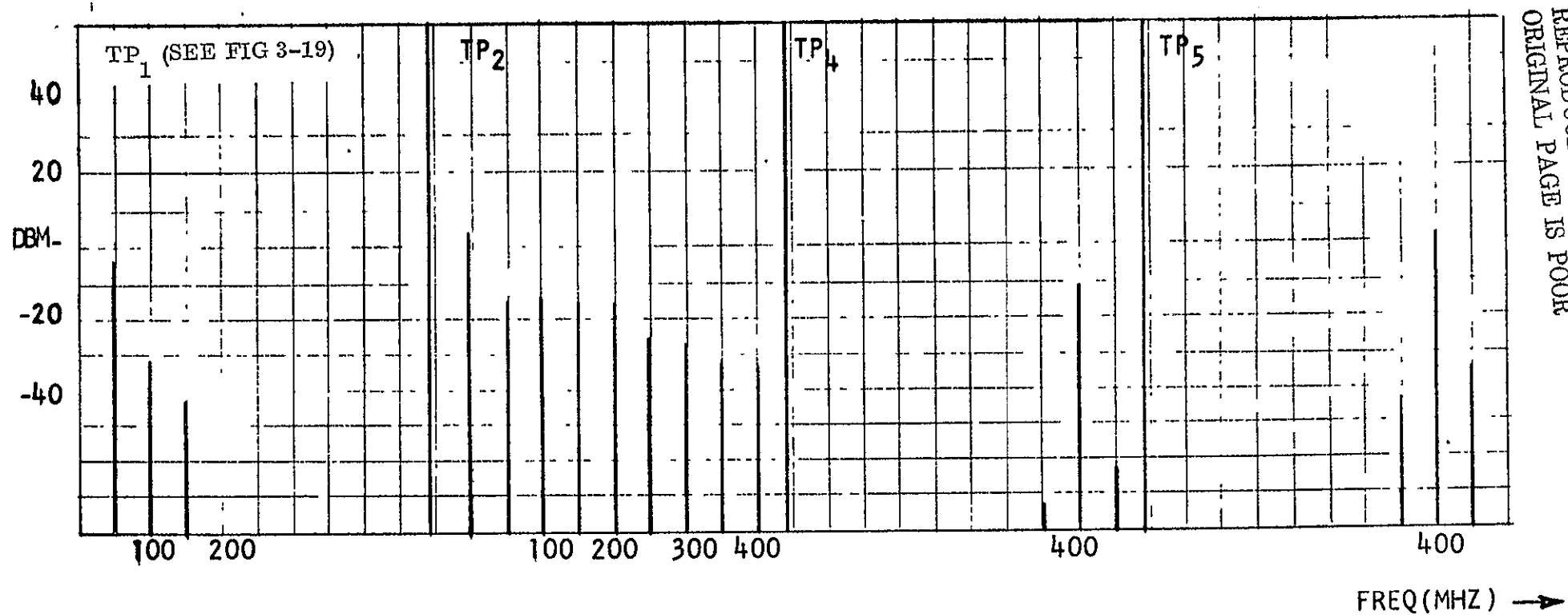


Figure 3-20. Signal Spectra; Saturated Amplifier Multiplier

3.5 PHASE MODULATOR

Two types of phase modulator were considered for the program. One produces the required phase shift (± 0.1375 radian) at 50 MHz. The second modulator operates at 400 MHz. The phase shift at 50 MHz is multiplied by 8 to obtain ± 1.1 radians.

3.5.1 50 MHz Phase Modulator

Figure 3-21 is a schematic diagram of the 50 MHz phase modulator. The resistive pads at the input and output of the modulator insure constant source and load impedance over temperature and input power variations. The required three phase states (-0.1375 , 0 & $+0.1375$ radians) are achieved by switching CR1 and CR2. Figure 3-22 is an equivalent circuit of the modulator. The resistors marked R represent the input and output impedances of the resistive attenuator pads of Figure 3-21, R is approximately 50 Ohms. The switch S represents either CR1 or CR2 and C represents either C1 or C2 of Figure 3-21. The transfer function for Figure 3-22 is (by inspection):

$$\frac{V_0}{V_1} = \frac{\frac{R}{J\omega C}}{R + \frac{1}{J\omega C}} = \frac{\frac{R}{1 + J\omega CR}}{R + \frac{R}{1 + J\omega CR}} = \frac{1}{2 + J\omega CR}$$

$$\left| \frac{V_0}{V_1} \right| = \frac{1}{\sqrt{4 + \omega^2 R^2 C^2}} \quad \text{MAGNITUDE OF TRANSFER FUNCTION}$$

$$\phi = -\tan^{-1} \left(\frac{\omega RC}{2} \right) \quad \text{PHASE SHIFT (RADIAN)}$$

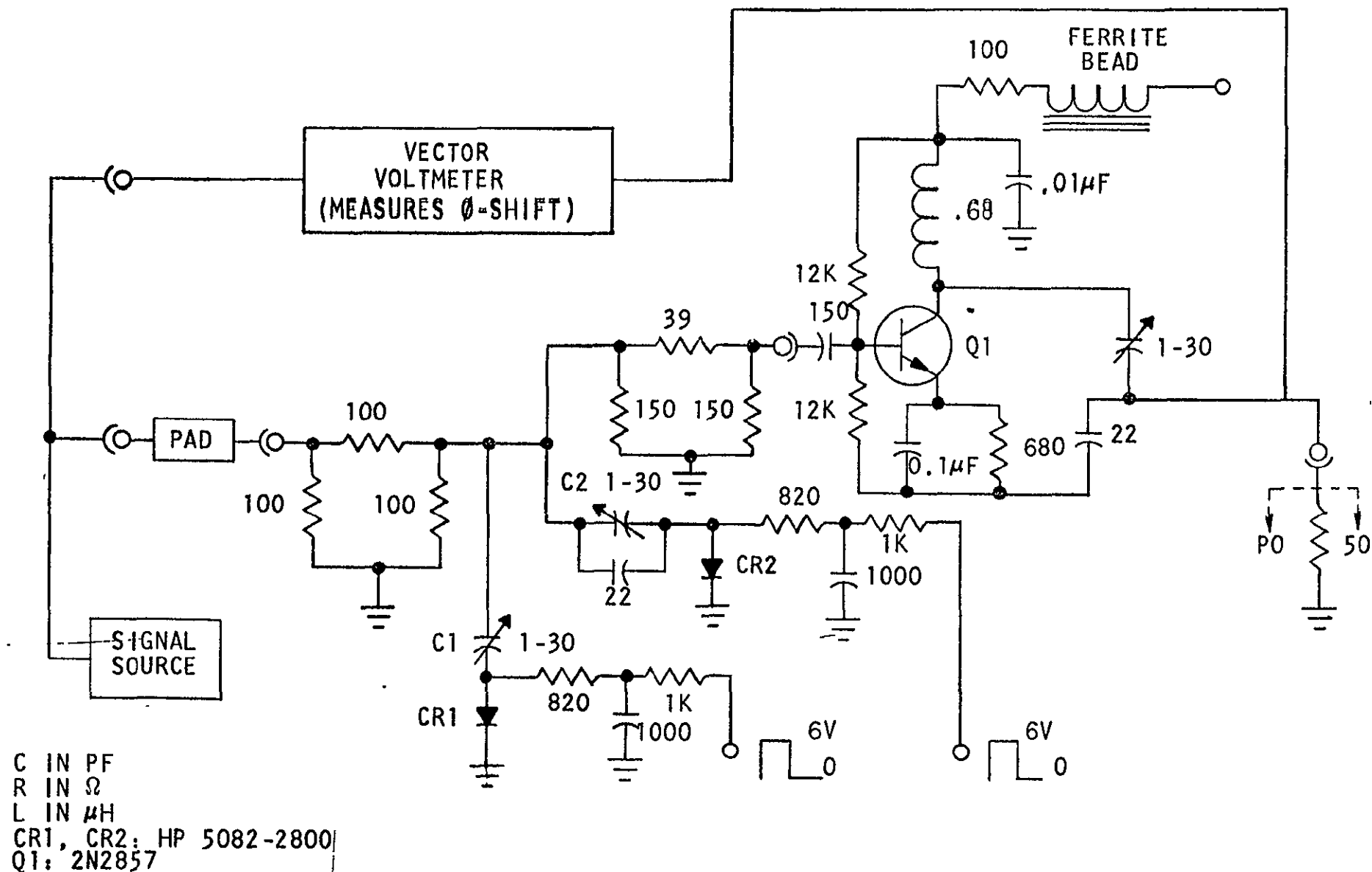


Figure 3-21. 50 MHz Phase Modulator

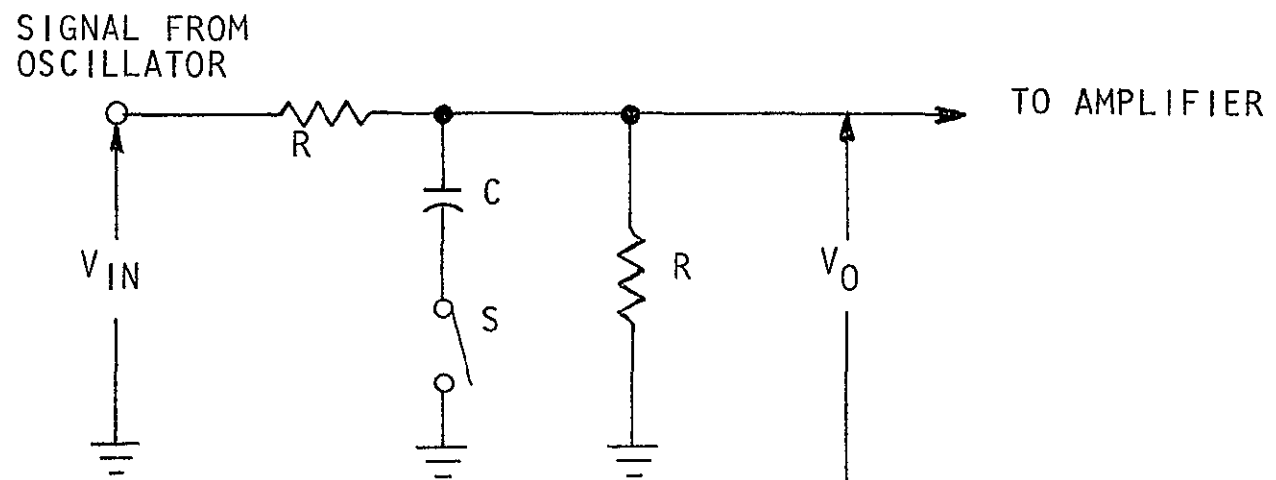


Figure 3-22. Phase Modulator Equivalent Circuit

Also, since $\text{TAN } \phi = \frac{\omega RC}{2}$

$$\frac{V_0}{V_1} = \frac{1}{2 \sqrt{1 + (\text{TAN } \phi)^2}}$$

The required system phase shift at the final frequency (400 MHz) is ± 1.1 radians (63°). Therefore, the phase shift required at 50 MHz is 0.138 radians (7.87°). The phase shift used in testing the phase modulator was 7° . The required value of C for a 7° phase shift is

$$C = \frac{2 \text{ TAN } \phi}{\omega R} = 15.6 \text{ Pico-Farads}$$

which is an entirely practical value.

Table 3-4 shows the performance of the phase modulator for various input levels. There are three important things to notice in Table 3-4: the phase shift remained constant as the input signal level changed and that the system power output changed very little as the phase was changed. Also, since a 2 db pad between the oscillator and phase modulator changed the phase modulation little, the phase modulator amplifier (Q_1 of Figure 3-21) is saturated.

Pad (See Fig. ϕ -1)	$\Delta\phi$	$P_o(\text{mW})$
0 db	-7	5.4
	0	5.4
	+7	5.0
2 db	-7	5.0
	0	5.0
	+7	4.3
3 db	-7	4.8
	0	4.6
	+7	3.8
4 db	-7	4.5
	0	4.4
	+7	3.5
6 db	-7	3.4
	0	3.2
	+7	2.4

Table 3-4. Phase Modulator Performance

3.5.2 400 MHz Phase Modulator

The 400 MHz phase modulator is shown in Figure 3-23. The pi-resistor networks at the input and output are 4 db attenuators. These attenuators are required to maintain a constant load and source impedance and, therefore, a constant phase shift over temperature. DL_1 and DL_2 are sections of UT34 semi-rigid transmission line wound on a 3/16" diameter form. The length of DL_1 is chosen to phase shift a signal 1.1 radian (63°) at 400 MHz. The length of DL_2 yields a phase shift of 2.2 radians (126°). The phase shift through the shorted leg of the phase modulator is taken as the reference for the above phase shifts. If the 63°

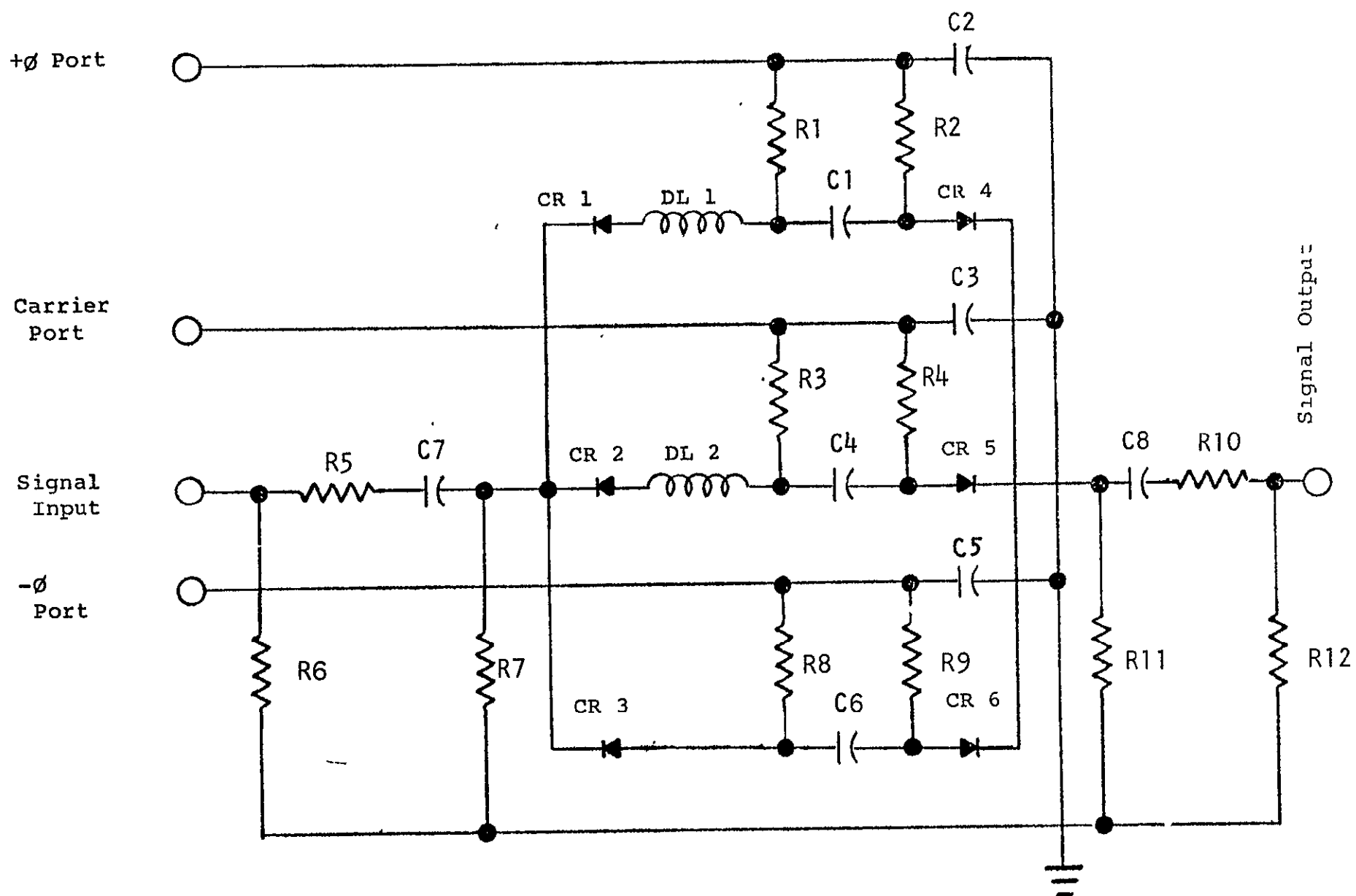


Figure 3-23. 400 MHz Phase Modulator

phase is considered as the unmodulated carrier phase then the other two phase shifts will lie $\pm 63^\circ$ about the unmodulated carrier phase.

Application of a positive going digital signal to any of the phase modulation ports gates on the diodes in the chosen port and inserts a section of transmission line in the signal path. Since the two ports not gated "on" are at ground potential, they are gated "off" by the digital signal. The insertion loss of the phase modulator including the pads is 10 db.

3.5.3 Comparison of Phase Modulators

Advantages of the 50 MHz multiplier are:

- 1) Requires only two lost cost diodes (quantity 100 - 999, \$1.05 ea.)
- 2) The gain required to overcome the loss in the modulator is easier to achieve @ 50 MHz.
- 3) Only two digital control lines are required to drive the modulators

Disadvantages of the 50 MHz multiplier:

- 1) Since the phase shift at 50 MHz is multiplied by 8 at the final output frequency (400 MHz), any change in phase (due to component drift) is multiplied by 8.
- 2) If the system phase shift is to be measured at the output frequency (in a test set) the reference signal for the test must come from the circuits before the phase modulator. In the case of the 50 MHz modulator, the 50 MHz reference signal must be multiplied up to 400 MHz in the test set.

Advantages of the 400 MHz Modulator

- 1) Since the modulation takes place after frequency multiplication any errors or drift in the modulation is not multiplied by 8 but appears directly in the output signal. Therefore, the performance over temperature is excellent.
- 2) The phase shifting elements of the modulator are lengths of semi-rigid coax (UT-34) which are quite stable over time and temperature.

Disadvantages of the 400 MHz Modulator

- 1) The primary disadvantage of the phase shifter is the cost of the diodes (HP 5082-3039) required at 400 MHz (\$3 each in quantity 100 - 999).

Despite the slightly higher cost, the 400 MHz multiplier was used in the final system because of its greater stability.

3.6 POWER AMPLIFIER

Two power amplifiers were considered for the system in our study effort: an AEL designed unit consisting of discrete components and a hybrid amplifier produced by Amperex.

Figure 3-24 shows the AEL Amplifier. The amplifier has two stages. A common emitter driver stage and a common base output stage. Data on the individual stages are given in Figures 3-25 and 3-26. The transistors in both stages are intended for 900 MHz service. They are used here at 400 MHz to achieve high efficiency operation. The sensor in the output stage provides a temperature varying bias current to the output transistor. This is done to keep the output power constant over temperature variations.

The second power amplifier considered is the Amperex BGY 22. This is a commercially available hybrid amplifier. Data sheets on this amplifier are given in Appendix II.

Detailed data: efficiency, power output over temperature, etc., is given for both power amplifiers in the section on system performance. The table below briefly compares the two amplifiers.

	AEL AMP.	BGY22
Voltage required for 3 W output (Volts)	12.5	15
Efficiency (%)	60-70	40-50
Variation in power output over temp range -40°C to +45°C (db)	± 0.25	± 0.5

The fact that the AEL amplifier requires only 12.5 volts rather than 15V means that the system battery can have fewer cells and therefore a smaller power supply is used. Also the greater efficiency of the AEL amplifier allows use of a lower amp-hour battery for equivalent operation. Since small size and long battery life are prime design goals for the MDCP, the AEL amplifier is clearly superior to the BGY22 for use in the MDCP.

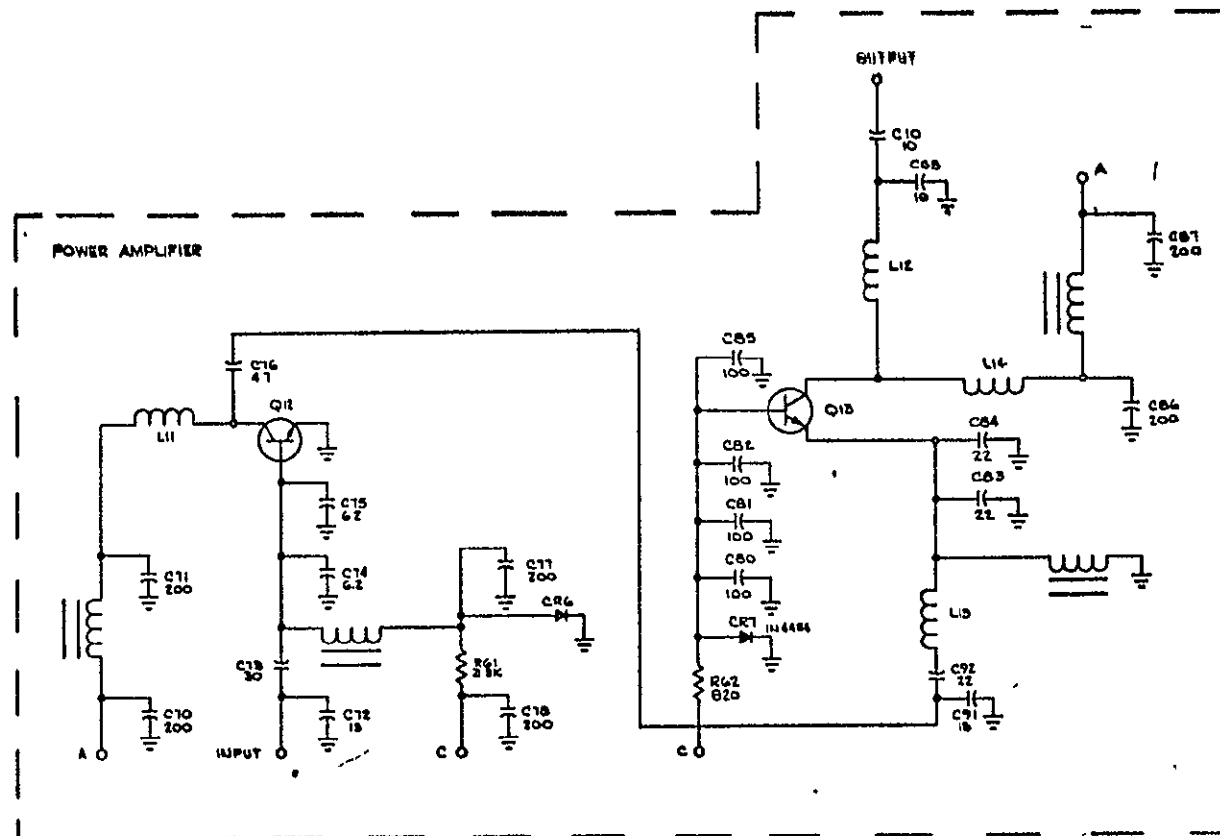


Figure 3-24. Power Amplifier

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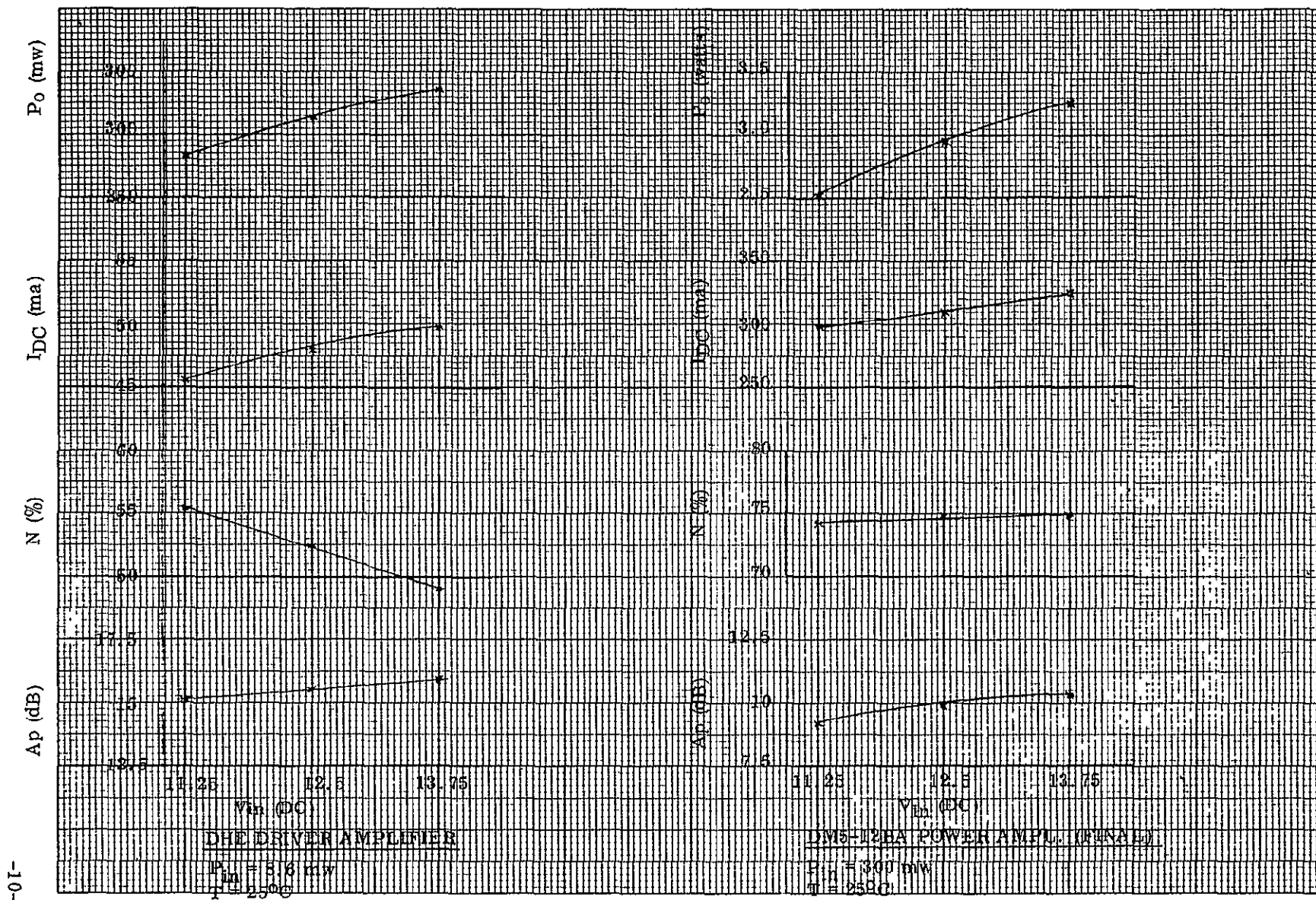


Figure 3-25. Test Results

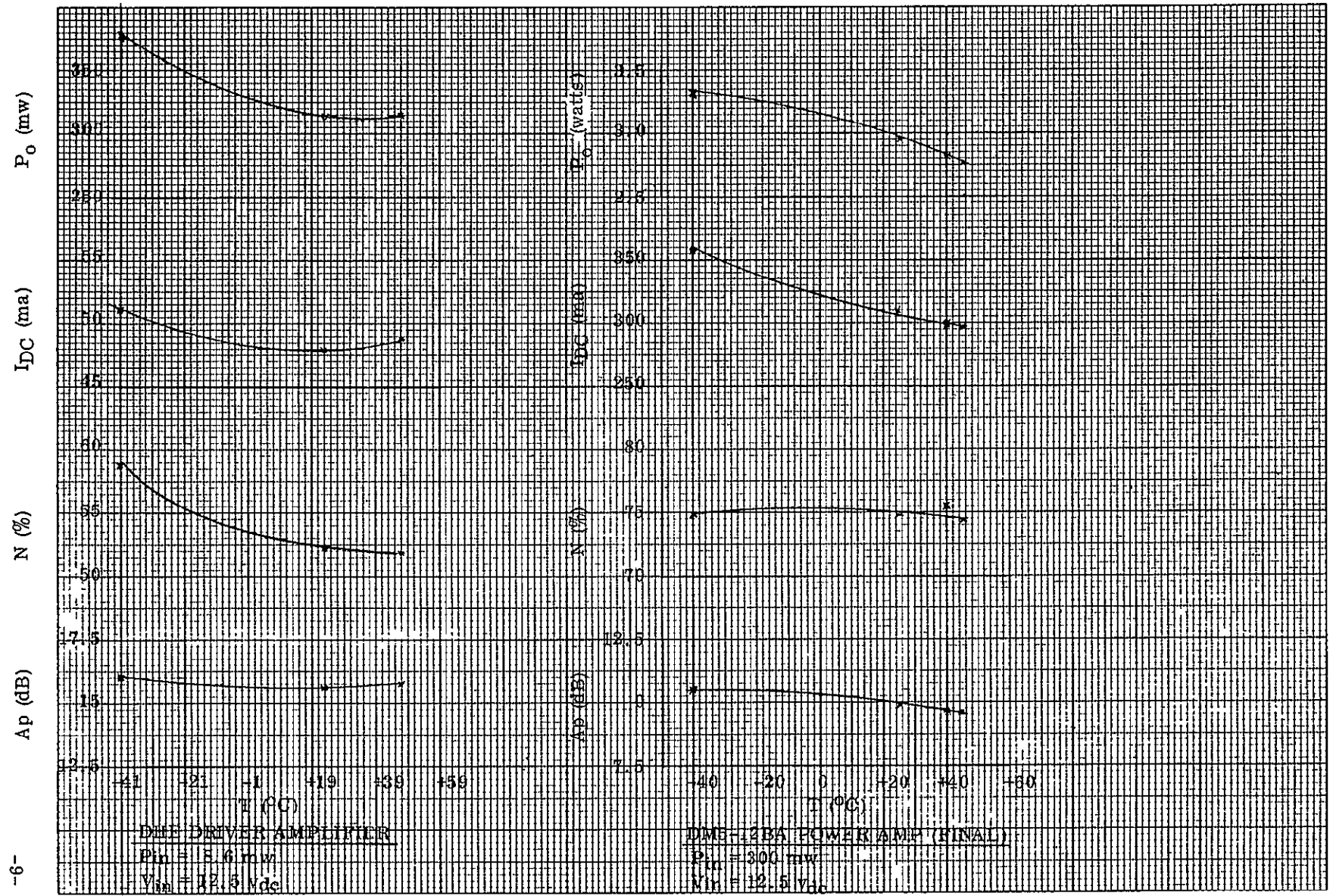


Figure 3-26. Test Results

SECTION 4

MINIATURE DATA COLLECTION PLATFORM (MDCP) SYSTEMS

4.1 INTRODUCTION

The system building blocks discussed in the previous sections were used to assemble, test and evaluate three MDCP systems. The selection of building blocks for each system is shown in Table 4-1. The most important features of each system are also given in Table 4-1. Each MDCP system discussed consists of an RF oscillator, multiplier and a power amplifier providing 3 watts of RF power output at 401.6 MHz.

Model	Multiplier	Phase Mod.	Pwr. Amp.	Characteristics
MDCP1	Tuned Transistor	400 MHz	AEL	High efficiency; long battery life. Requires considerable tuning and is, therefore, more costly to produce than MDCP2 or MDCP3. Nominal battery voltage required: 12.5V for 3 W output.
MDCP2	SAT Amp.	400 MHz	BGY22	Lower efficiency than MDCP1. However, unit requires almost no tuning and is lower in cost than MDCP1. Nominal battery voltage: 15V for 3 W output.
MDCP3	Tuned Transistor	400 MHz	BGY22	This unit is the same as MDCP1 with the high efficiency amplifier replaced by the BGY22. MDCP3 lies approximately midway between MDCP1 and MDCP2 in characteristics. Nominal battery voltage: 15V for 3 W output.

Table 4-1. MCDP Characteristics

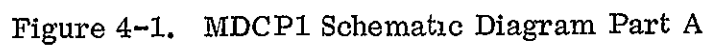
The MDCP is a pulsed system which normally transmits for 380 to 920 millsec of an interval ranging from 40 to 200 Seconds. During transmission each unit transmits 3 Watts and requires approximately 0.4 Amp. from the battery. The MDCP also draws a continuous current of approximately 2.0 milli-ampere from the battery for the system RF oscillator. The RF oscillator is usually run continuously to insure good RF output frequency stability.

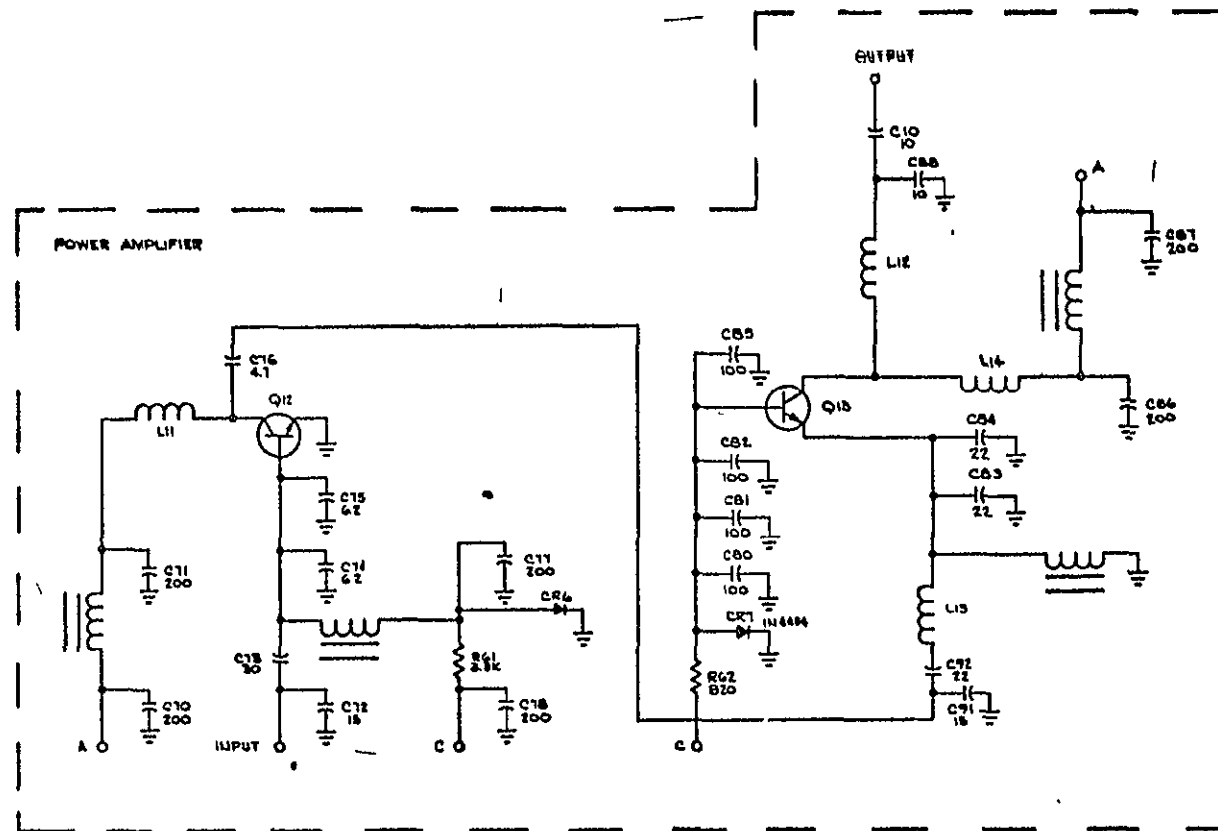
4.2 MINIATURE DATA COLLECTION PLATFORM 1 (MDCP1)

Figures 4-1 are schematic diagrams of the MDCP1. A parts list for MDCP1 is provided in Appendix III. The system operates from a nominal 12.5 power source uses a transistor multiplier, 400 MHz phase modulator and the AEL high efficiency amplifier. The size and weight of the system is 6.75 x 17.5 x 1.56 (CM) and weighs 143 GMS. The volume is 185 CM³. The preceeding figures are for the system constructed as a printed circuit card and includes an RF amplifier heat sink.

Figure 4-2 A and B give temperature vs. frequency data on the system for five crystals. Figure 4-2A shows the uncompensated system performance and Figure 4-2B the compensated performance. It is evident from figure 4-2B that the compensated oscillators have $\Delta f/f$ of ± 3 PPM from -40 to +45°C. Table 4-2 gives temperature test data on MDCP1. In Table 4-2, I_{DC1} is the current to the power amplifier alone. I_{DC2} is the total system current. The short term stability of MDCP1 (at 25°C) is given below. Each measurement is the average of 100 samples. The measurements were made on a Hewlett-Packard 5360A Computing Counter.

MEASUREMENT INTERVAL	
100 Millisec	1 Sec
0.9×10^{-10}	1.9×10^{-10}
0.87×10^{-10}	1.5×10^{-10}
0.86×10^{-10}	1.4×10^{-10}
0.9×10^{-10}	1.0×10^{-10}
0.9×10^{-10}	1.2×10^{-10}
0.9×10^{-10}	1.7×10^{-10}





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Figure 4-1. Power Amplifier Part B

Figure 4-2A. $\frac{\Delta f}{f}$ Uncompensated System

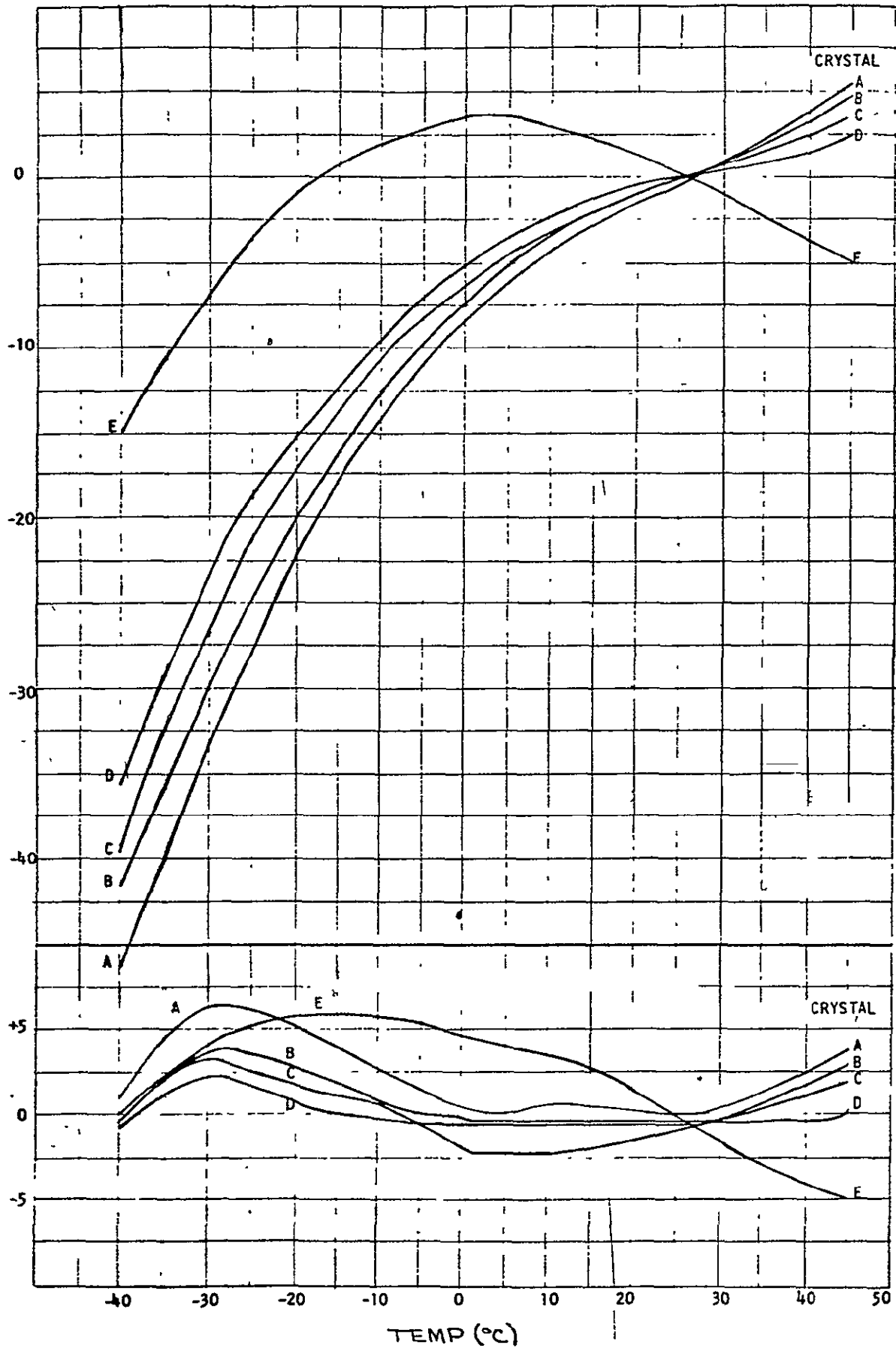


Figure 4-2B. $\frac{\Delta f}{f}$ Compensated System

Temp.		-40°C	-30°C	-20°C	-10°C	0°C	+10°C	+20°C	+25°C	+35°C	+45°C
Freq.	H _Z	401 652030	401 654222	401 654794	401 653931	401 653246	401 652729	401 652347	401 652213	401 652025	401 652258
2nd Harmonic	DB	-43	-44	-45	-45	-45	-45	-45	-45	-45	-45
P _{out}	W	2.35	2.35	2.35	2.3	2.3	2.25	2.25	2.2	2.15	2.1
I _{DC1}	ma	360	360	360	360	350	340	340	330	330	320
I _{DC2}	ma	400	400	400	400	390	390	390	390	380	370
V _{cc}	V	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25
+ ϕ Mod	Deg	64	66	69	68	68	68	68	68	68	68
- ϕ Mod	Deg	65	65	66	65	64	64	64	63	64	64
Freq	H _Z	401 652038	401 654221	401 654796	401 653931	401 653249	401 652730	401 652349	401 652222	401 652029	401 652259
2nd Harmonic	DB	-43	-44	-45	-45	-45	-45	-45	-45	-45	-44
P _{out}	W	2.9	2.9	2.9	2.85	2.85	2.85	2.80	2.75	2.7	2.6
I _{DC1}	ma	400	390	390	380	380	370	370	360	360	350
I _{DC2}	ma	440	430	430	420	420	430	430	420	420	410
V _{cc}	V	12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50
+ ϕ Mod	Deg	64	65	69	68	68	68	68	68	68	68

Table 4-2. Temperature Test Data

Temp.		-40°C	-30°C	-20°C	-10°C	0°C	+10°C	+20°C	+25°C	+35°C	+45°C
~ ϕ Mod	Deg	64	64	66	65	65	64	64	64	64	64
Freq	H _Z	401 652042	401 654220	401 654801	401 653933	401 653247	401 652732	401 652350	401 652230	401 652038	401 652253
2nd Harmonic	DB	-42	-43	-44	-44	-44	-44	-44	-44	-45	-45
P _{out}	W	3.6	3.6	3.6	3.5	3.5	3.5	3.4	3.3	3.1	3.1
I _{DC1}	ma	420	420	420	410	410	400	400	390	390	380
I _{DC2}	ma	460	460	460	450	450	450	450	440	420	430
V _{cc}	V	13.75	13.75	13.75	13.75	13.75	13.75	13.75	13.75	13.75	13.75
+ ϕ Mod	Deg	64	64	68	68	68	68	68	68	68	68
~ ϕ Mod	Deg	64	64	64	64	64	64	64	64	64	64

Table 4-2. Temperature Test Data (cont)

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4.3 MINIATURE DATA COLLECTION PLATFORM 2 (MDCP2)

Figure 4-3 is a schematic diagram of the MDCP2. A parts list is given in Appendix III. The MDCP2 uses the saturating amplifier multiplier, 400 MHz phase modulator and BGY22 power amplifier. The system operates from a nominal 15V power supply because the BGY22 RF amplifier requires 15V for 3 watt output. The size and weight of the MDCP2 is 3.75 x 5 15 (CM) and 180 GMS. The volume is 281 CM^3 . Here (as in the MDCP1) the size, weight and volume includes the circuit constructed as a printed circuit card including the power amplifier heat sink. Table 4-3 gives temperature test data on the MDCP2. As can be seen from table 4-3 the RF output power held ± 0.5 db from -40°C to $+45^\circ\text{C}$ and the phase modulation changed $\pm 1^\circ$ over the same temperature range. The largest harmonic output (2nd harmonic) was greater than 25 db below the carrier over the temperature range.

4.4 MINIATURE DATA COLLECTION PLATFORM 3 (MDCP3)

Figure 4-4 is a schematic of MDCP3. Appendix III contains a parts list for MDCP3. The MDCP3 is similar to the MDCP1. The only difference is that MDCP3 uses the BGY22 RF amplifier instead of the AEL high efficiency amplifier. As a result, the MDCP3 is lower cost than the MDCP1 but also has lower efficiency. The size, weight and volume of the MDCP3 is 6.25 x 15 x 1.6 (CM), 88 GMS and 150 CM^3 . The system operates from a nominal 15 volt power source. Table 4-4 gives temperature test data on the system.

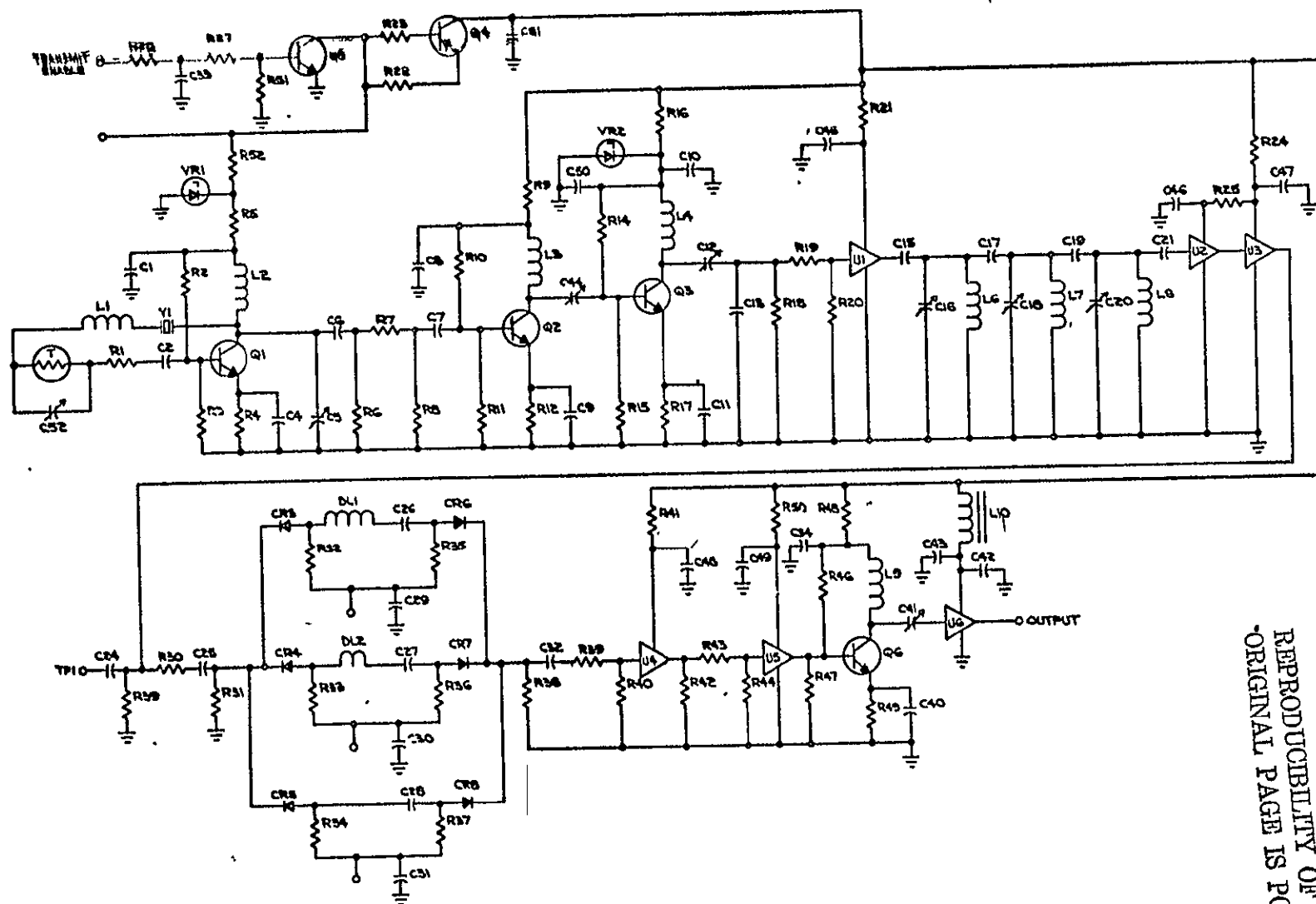
4-5. System Evaluation

This section will evaluate the three systems against battery size, power amplifier efficiency, life time and will show how each could be matched to an end system use.

Figure 4-5 is a plot of Battery capacity vs. operating life for MDCP1, 2 and 3. The operating life of each system is shown as preshaped segment, rather than a single line, to account for the variation of power amplifier efficiencies (E_{PA}) which is unavoidable in a production run. Figure 4-5 is plotted for a typical transmission interval of 700 millisecond, 50 second interval between transmissions and RF power output of 3 Watt. The total system efficiencies (E_T) are shown for the three systems. The data of Figure 4-5 was plotted for a quiescent current (I_Q) of 2.5 milli-ampere. The quiescent current is required for the RF oscillator and the systems (assumed) digital clock. This current is required between transmissions as well as during transmission.

Temp °C	P _{out} W	I _{DC} ma	+ Phase Deg.	- Phase Deg.	2nd Harmonic -dB	Eff %
+45	3.7	680	64	65	-26 dB	36
+35	3.8	690	65	65	-26 dB	37
+25	3.9	690	65	65	-26 dB	38
+15	4.1	695	65	65	-26 dB	39
+5	4.2	695	65	65	-26 dB	40
0	4.4	700	64	65	-25 dB	42
-10	4.4	695	63	65	-25 dB	42
-20	4.5	690	63	65	-25 dB	43
-30	4.5	680	63	64	-25 dB	44
-40	4.6	680	63	64	-25 dB	45

Table 4-3. MDCP2 Test Data



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Figure 4-3. MDCP2

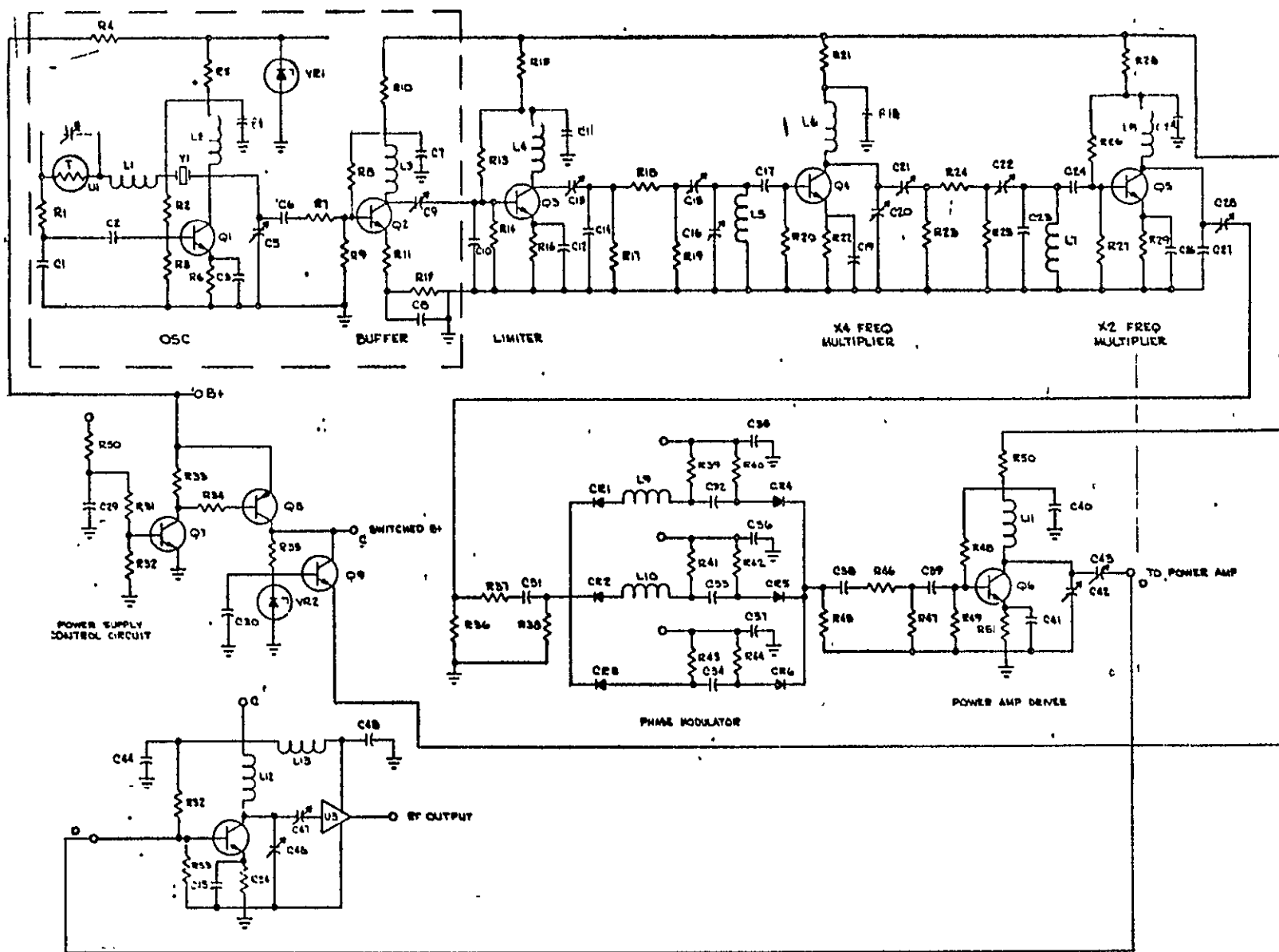


Figure 4-4. MDCP3

V _{Battery} (Volts)	P _o (Watt)	I _{Battery} (Amp)	System Efficiency (%)	Temp (°C)
15.4	3.1	0.63	32	+45
14.0	2.5	0.58	31	
12.6	2.0	0.52	31	
15.4	3.2	0.65	32	+35
14.0	2.8	0.59	34	
12.6	2.2	0.52	34	
15.4	3.4	0.64	34	+25
14.0	2.8	0.59	34	
12.6	2.2	0.53	33	
15.4	3.5	0.65	35	+10
14.0	3.0	0.58	37	
12.6	2.3	0.52	35	
15.4	3.6	0.65	36	0
14.0	2.9	0.56	37	
12.6	2.3	0.53	37	
15.4	3.4	0.60	37	-10
14.0	2.9	0.56	37	
12.6	2.3	0.51	37	
15.4	3.5	0.62	38	-20
14.0	2.8	0.55	37	
12.6	2.2	0.49	36	
15.4	3.1	0.58	35	-30
14.0	2.5	0.522	34	
12.6	2.0	0.46	35	
15.4	2.6	0.53	32	-40
14.0	2.1	0.46	32	
12.6	1.6	0.40	32	

Table 4-4. Temp. Test Data, MDCP3

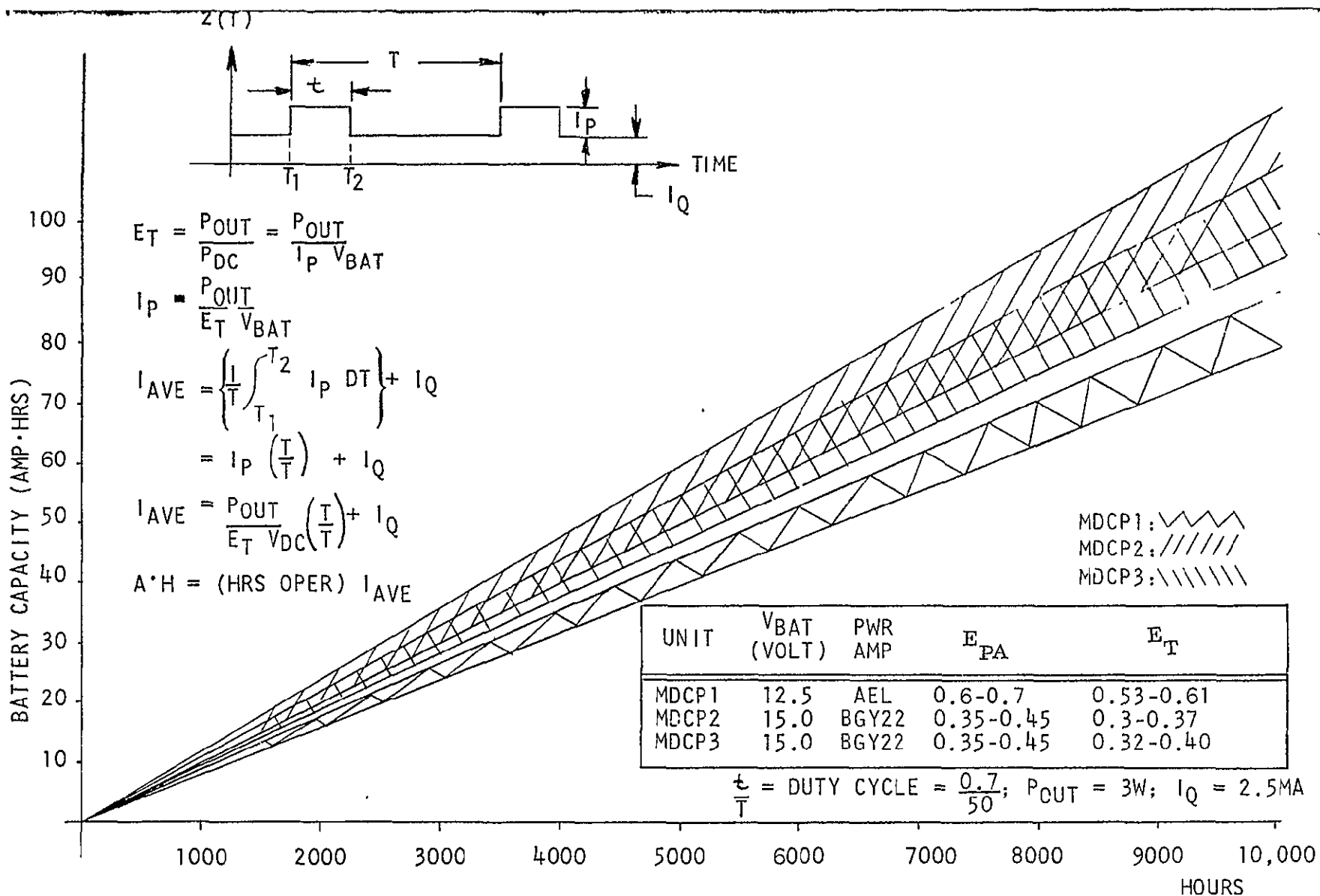


Figure 4-5. Operating Life; MDCP

At any chosen operating lifetime, (except below 1500 hours) the MDCP1 requires considerably less battery capacity than the MDCP1 or MDCP2. The improved battery life of the MDCP1 is due to the AEL high efficiency amplifier (60% to 70% efficiency) as compared to the BGY22 power amplifier (35% to 45% efficiency).

MDCP2 and MDCP3 are almost identical in battery capacity characteristics. However, MDCP2 has almost no tuning since it used integrated broadband amplifiers for frequency multiplication and amplification at 400 MHz. In large quantities (1000 and up) these amplifiers would be very low cost. Therefore, MDCP2 has a distinct cost advantage over MDCP3 and MDCP1 where large quantities are required and battery size is not paramount. Since MDCP2 consists largely of integrated amplifiers it offers the most potential advantage for size reduction.

Battery size must be considered in any discussion of system size since a 10 A·H Lithium Sulphur Dioxide battery — the highest energy density battery available — at 15V is 6.9 x 2.5 x 1.4 inches. Therefore, for systems requiring batteries of 10 A·H or greater capacity, extreme size reduction of the MDCP does little to reduce the overall system size.

Many applications of the MDCP will not require continuous operation of the system. Animal telemetry is one example of such an application. In such an application the MDCP can be gated on and off to prolong battery life. When the system is off only the digital clock requires current ($I_D = 0.5 \text{ mA}$) the MDCP can be gated on for 8 hours each day. Figure 4-6 shows that for such a gating scheme a 10 A·H battery will provide 3000 hours operation of MDCP1. Figure 4-6 gives the operating life of MDCP1 powered from a 10 A·H battery when the system is on for 8 hours out of every T hours. If the system is operated 8 hours every two days the system operating time (from Figure 4-6) is approximately 5500 hours. T_0 in Figure 4-6 is the warm-up time allowed for RF oscillator before the transmission interval. I_0 is the current required by the RF oscillator.

The benefits of gating the system are also shown in Figure 4-6A. Here, the battery capacity is shown as a function of the gating period (T_T/T) with the transmission period as a running parameter. The values of t/T plotted are typical of an actual system. Note that the curves do not go to zero battery capacity for $\frac{T_T}{T} = 0$. This is due to the current (I_D)

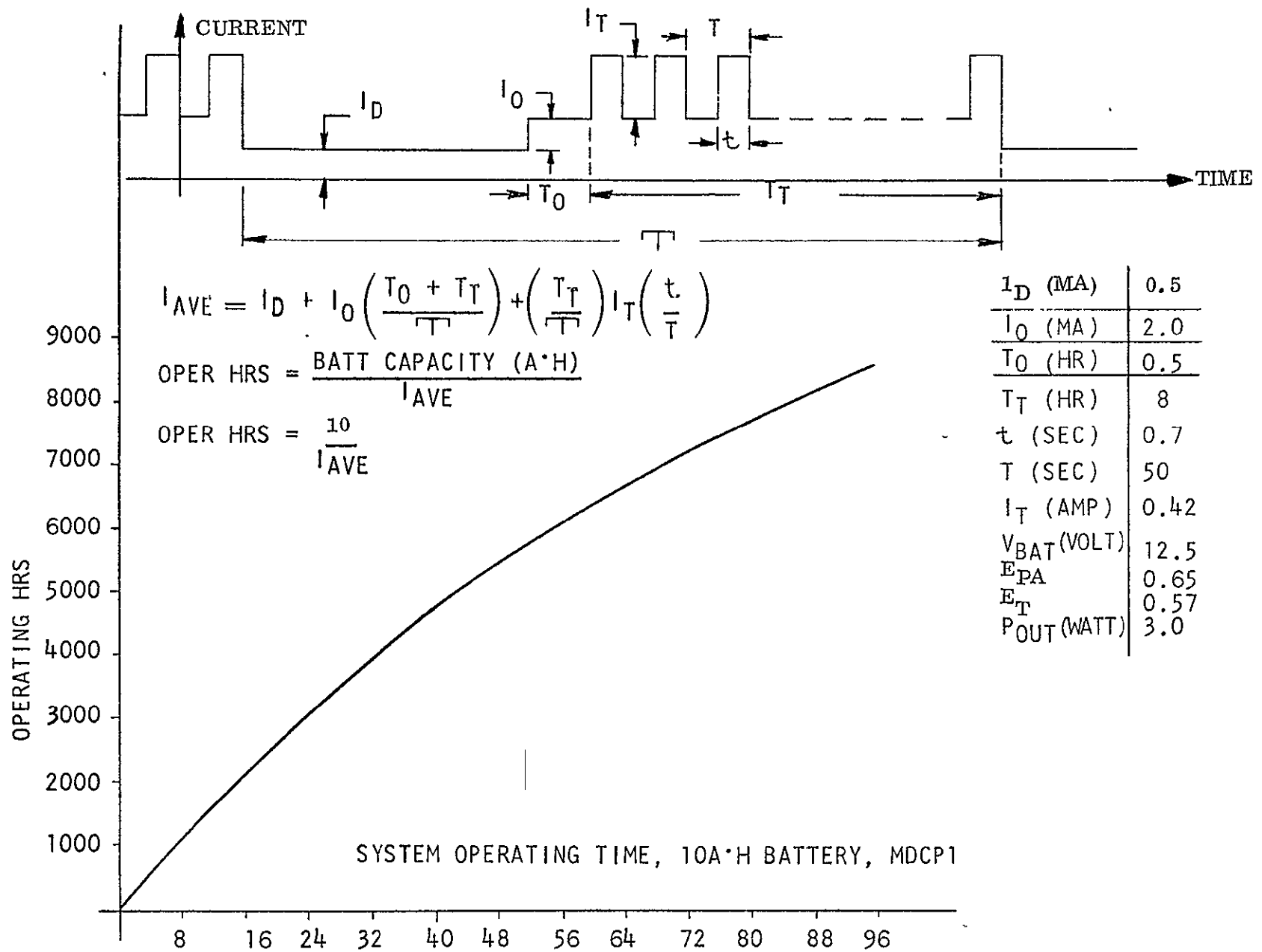
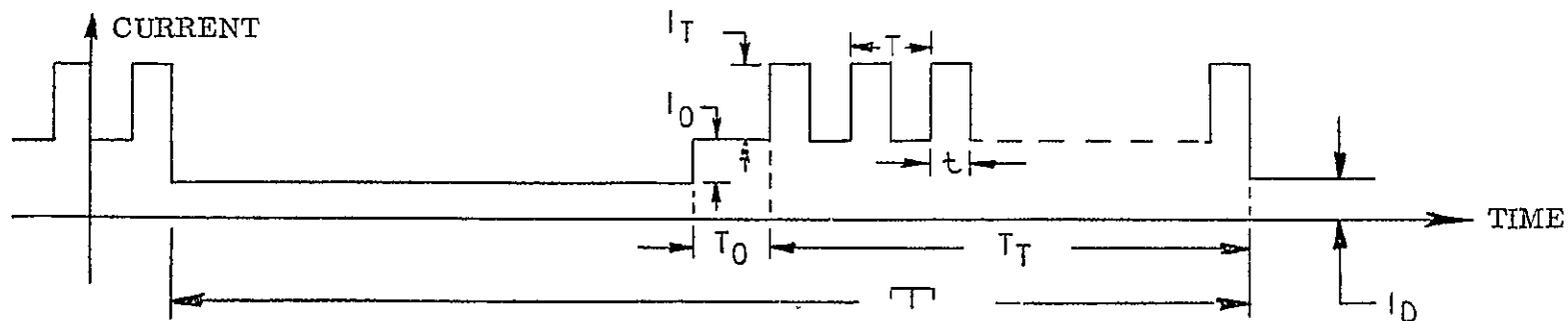


Figure 4-6. Operating Period (T) Hrs.



$$I_{AVE} = I_D + I_0 \left(\frac{T_0}{T_T} + \frac{T_T}{T_T} \right) + \frac{T_T}{T_T} (I_T) \left(\frac{t}{T_T} \right)$$

$$I_{AVE} \approx I_D + I_0 \left(\frac{T_T}{T_T} \right) + \frac{T_T}{T_T} (I_T) \frac{t}{T_T}; \text{ WHERE } \frac{T_0}{T_T} \ll \frac{T_T}{T_T} \text{ IS ASSUMED}$$

$$\text{BATTERY CAPACITY (A*H)} = I_{AVE}(\text{OPERATING HRS})$$

I_D (MA)	0.5
I_0 (MA)	2.0
I_T (AMP)	0.42
V_{BAT} (VOLT)	12.5
E_{PA}	0.65
E_T	0.57
P_{OUT} WATT	3.0

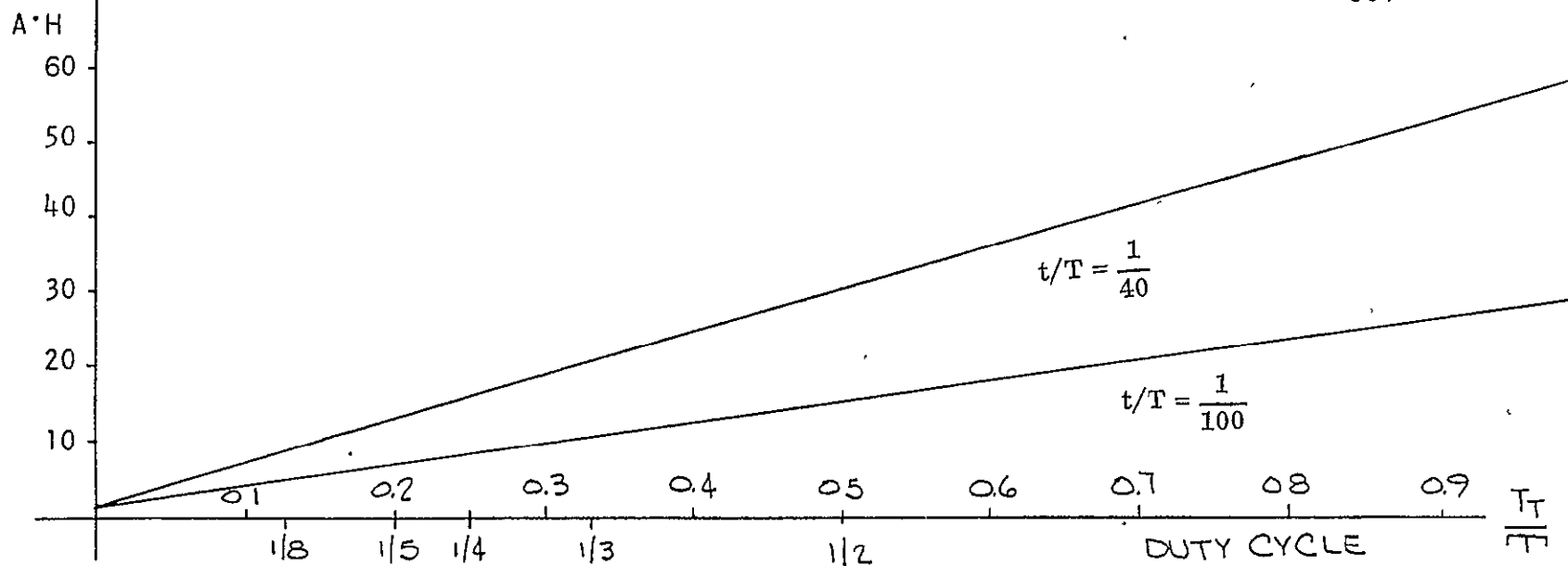


Figure 4-6A. Battery Capacity Required for 6 Months Operation of MDCP1

required to maintain a digital system clock. For an estimated $I_D = 0.5 \text{ mA}$, 6 months system operation requires $2.2 \text{ A}\cdot\text{H}$ of battery capacity for the clock.

The preceding paragraph discussed a battery saving technique whereby the entire system, except the digital clock, was shut down between transmissions. This technique is useful in applications requiring data for only a fraction of each day or a fraction of each two days, etc. In applications requiring continuous transmission, for example, 700 milli-sec out of each 50 seconds another battery saving technique is applicable. Experiments performed on the MDCP1 indicate that the system oscillator will stabilize in 15 seconds. That is, the RF oscillator can be shut down for 35 seconds of the 50 second non-transmit interval. If the system transmission characteristics were: transmit 700 milli-sec of each 200 second interval, then turning on the oscillator 15 seconds prior to transmission would reduce the average current required by the RF oscillator from 2 mA to 0.15. When the RF oscillator is not gated a continuous 2 mA is drawn from the battery. This current drain requires $2 \text{ A}\cdot\text{H}$ of battery capacity for each 1,000 Hrs. of system operation. When the RF oscillator is gated the average oscillator current (I_{OAVE}) becomes

$$I_{\text{OAVE}} \approx (2 \text{ mA}) \frac{15}{T}$$

where T is the interval between transmissions. The subsequent reduction in required battery capacity (ΔC) is

$$\Delta C = (\text{Oper Hrs}) (2 \times 10^{-3}) \left(1 - \frac{15}{T}\right)$$

Figure 4-7 is a plot of ΔC vs. operating hours for various values of T. Figure 4-7 can be used with Figure 4-5 to estimate battery savings by gating. For instance, take the overall efficiency (E_T) of MDCP1 to be midway between the extremes plotted in Figure 4-5; i.e., $E_T = 0.57$. Then from Figure 4-5; one half year operation (4382 hrs.) of the ungated system requires a battery capacity of $36 \text{ A}\cdot\text{H}$. Gating the system will save (from Figure 4-7, $T=50$) $6.14 \text{ A}\cdot\text{H}$ of battery capacity. A 17% saving in battery capacity results.

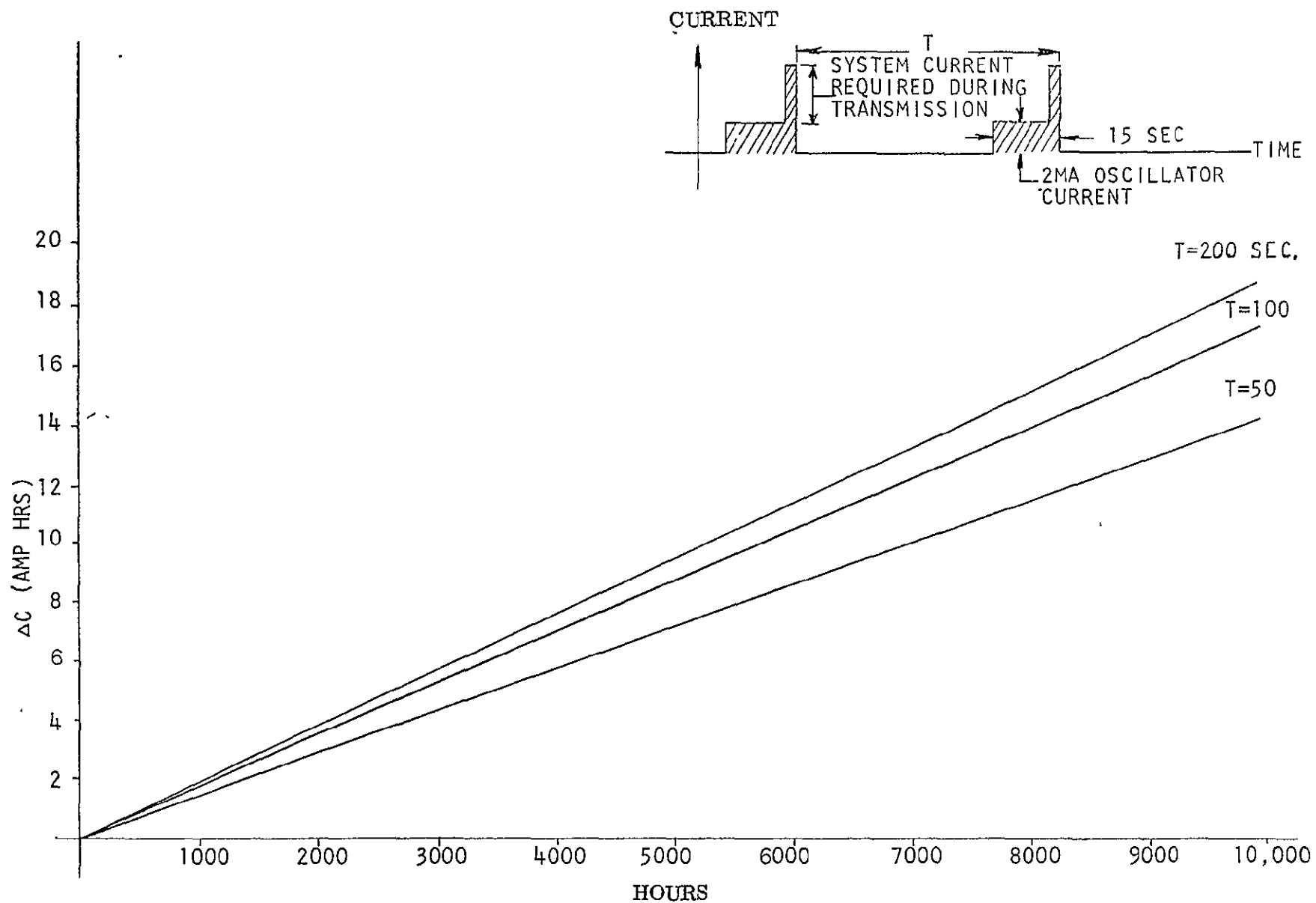


Figure 4-7. Operating Hours

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SECTION 5

RECOMMENDATIONS

5-1 MODULAR SYSTEMS

It is recommended that a modular system concept be applied to further the development of a MDCP. There are many data collection satellite systems (GOES, TIROS, NIMBUS) and therefore many different DCP's. MDCP's developed on this program can serve as a nucleus for a universal MDCP. That is, a platform which will be useful in any satellite system and within any system be versatile enough to satisfy most users. This modular system would require a micro-processor digital subsystem which could be programmed to provide the appropriate digital format for each system and a modular RF package that would allow the phase modulation and RF power output to be changed to suit a particular application. One will note that the system developed in the present program is modular and well suited to this purpose. The RF system, in general, is comparable in performance (power out, PSK, harmonics, frequency stability) for all the satellite systems.

5-2 SPECIALIZED DIGITAL SYSTEMS

The development of actual digital formatting and timing hardware was not part of this development program. However, the current consumption saving techniques and cost aspects tradeoffs are indeed an important factor of the MDCP system. Although microprocessor techniques are applicable, they tend to complicate the issue of simplicity for many users. For example, a wildlife user probably desires a specific miniature DCP package for a specific satellite system. Since his platform unit is sealed from the environment, he does not easily have the options of reprogramming for different satellite systems as well as different self-timed gating transmissions. However, the oceanographer or meteorologist has more control over the end product and usually has the time to incorporate the well-meaning features of the microprocessor.

With these factors in mind the unique features of a miniature DCP for the wildlife user should incorporate the following digital features:

- The logic unit should be hybridized in order to maintain the small size and low weight concepts.

- Low current A/D hybrid converters should be investigated to the fullest extent for tradeoffs in size, temperature range, conversion/accuracy error and other factors.
- Current saving techniques should be investigated to the fullest. It can be shown that the quiescent current could be reduced to 100 μ a. for the digital section.
- Packaging of the hybrid logic in its own hermetically sealed enclosure would vastly improve the reliability aspects.
- Operation of the logic at a 5-volt level would not only reduce the current drain but would in addition improve the system reliability.

5.3 SYSTEM TESTING AND EVALUATION

When one reduces the package size to an extremely small configuration it is important that all the subsystem parts be incorporated. The battery, logic section, antenna, antenna cable, transmitter and enclosure should have been part of the final configuration in order to properly test and evaluate the MDCP. Some of the obvious system problems are as delineated below:

- | | |
|----------|---|
| Battery: | Full analysis for peak current demand capability over the environmental temperature range. Determination of internal resistance as a function of quiescent/peak demand operation over a life cycle basis. This obviously results in a terminal voltage drop which affects system performance parameters. Determination of special handling, pressure capability for submerged fish, and other safety aspects when used with wildlife creatures. |
| Logic: | Determination of detrimental effect of RF radiation to logic package. The logic section has always been the poorest reliability subsystem in the DCP; further reliability tests should be performed. |

Antenna and
Associated Cable: An optimum small size antenna with its associated satellite pattern should have been fully evaluated. Power gains (ERP) incorporated in the antenna could have reduced the transmitter power output, thus easing the battery drain/size requirements. The antenna radiation effect on the logic/transmitter subsystem should be investigated. The antenna cable length can effectively transfer a complex impedance back to the transmitter output causing severe reliability problems. Associated with each antenna, there is a VSWR (impedance mismatch) which, because of line length (l), reflects a complex impedance ($R \pm j \theta$) to the power amplifier terminals.

System Grounding: The smaller the package, the harder it is to obtain good ground connections to protect against circulating ground loop problems. Each enclosure is predicated on its end use; i.e., it would be different for a porpoise as opposed to a turtle. These packages would indeed be different for other end users such as oceanographers. Shock and vibration aspects should also be fully investigated.

Transmitter: All of the above items play an important part to the RF frequency stability and phase stability of this high peak current source.

6. PLATFORM COSTS

The estimates for cost are shown in Table 6-1 for the MDCP-1 model developed under this program. It should be pointed out that these costs are only estimates and are not to be interpreted as quotations. It is obvious that a quotation for production units would require a more detailed analysis within areas of environmental testing, reliability, detailed schematics, test figs manufacturing drawings and other non-recurring cost items. The costs shown in Table 6-1 are for the recurring costs of (RF and digital) only and do not include the antenna, enclosure, or power supply sources. All costs shown are estimated "sell" costs which reflect overhead, general and administrative costs, and profit.

ITEM	COST (DOLLARS)
MATERIAL	310
LABOR	40
SELL PRICE	350

Table 6-1. Platform Estimated Costs (Quantity of 1,000)

Pricing for the digital package was based on interfacing with four analog channel inputs and that the total I.C. chip count (including A/D Converter) was less than twenty.

Trying to receive cost from manufacturers for quantities of 10,000 was extremely time consuming and in addition was not accurate. When a manufacturer realizes that pricing is required for quotation purposes only (and not a "real" purchase order) he tends to roughly estimate prices. More accurate costs were obtained for standard quantities and for that reason Table 6-1 reflects a quantity of 1,000 units.

APPENDIX I
PROGRAMS USED FOR
OSCILLATOR DESIGN CALCULATIONS

APPENDIX I

This appendix contains four programs for the Texas Instrument SR-56 programmable calculator. The first program is the most basic and solves the theoretical equation for the thermistor

$$\frac{R_T}{R_{25}} = \text{EXP} \left[B \left(\frac{1}{T} - \frac{1}{T_0} \right) \right]$$

along with the imaginary part of equation 7 and equation 6 for $\frac{\Delta f_0}{f_s}$. Therefore, for a given thermistor, crystal and capacitive reactance the program calculates $\frac{\Delta f_0}{f_s}$ for any value of $T(^{\circ}\text{C})$ entered into the display before starting the program.

The second program is a modification of the first program. Here, given a value of $\frac{\Delta f_0}{f_s}$ at some temperature $t = t_1$, the program searches for the value of X which yields $\frac{\Delta f_0}{f_s} / t = t_1$. The program does this by taking the value of X stored in memory register 4 and decrementing it in ΔX steps and calculating $\frac{\Delta f_0}{f_s}$ for each step. The calculated value of $\frac{\Delta f_0}{f_s}$ is checked against the value stored in R_T . When the calculated value equals or exceeds the desired value of $\frac{\Delta f}{f}$ the program stops. The value of ΔX is at the command of the programmer and is entered in steps 89 and 90 of the program. For example:

1 $\rightarrow$ 89 and 0 $\rightarrow$ 90 $\Rightarrow \Delta X = 10$ ohms
 5 $\rightarrow$ 89 and NOP $\rightarrow$ 90 $\Rightarrow \Delta X = 5$ ohms
 1 $\rightarrow$ 89 and NOP $\rightarrow$ 90 $\Rightarrow \Delta X = 1$ ohms

The program as shown on the coding form has $\Delta X = 10$.

The third program in this appendix was used to generate the compensation curves used on the program (Figures 3-3A & 3-3B of section 3). This program is a modification of program 1. The program automatically solves for $\frac{\Delta f_0}{f_s}$ for $-40^{\circ}\text{C} \leq t \leq 50^{\circ}\text{C}$, in 10°C steps for a given crystal, thermistor and capacitive reactance X .

The fourth program calculates the value of R_t (= the temperature varying resistance inserted in series with the crystal by the compensation scheme.) Here as in program 3 the program automatically steps through temperature from -40°C to $+50^{\circ}\text{C}$ in 10°C steps and computes and displays R_t at each step.

Each program has one or more test problems. The purpose of these problems is two-fold. First, they are useful in gaining familiarity with the programs. Secondly, once a program is keyed into the calculator they can be used to test for correct program entry.

PROGRAM #1

CRYSTAL COMPENSATION USING THERMISTOR/ CAPACITOR NETWORK

- This program solves the following eqns for $\frac{\Delta f_0}{f_s}$

$$\frac{R_T}{R_{25}} = \text{EXP} \left\{ B \left(\frac{1}{T} - \frac{1}{T_0} \right) \right\} \quad T, T_0, B \text{ in Deg Kelvin}$$

$$X_t = \frac{X}{1 + \frac{X^2}{R_T^2}}$$

$$\frac{\Delta f_0}{f_s} = \frac{X_t}{2r(X_t + X_0)}$$

X is assumed to be a capacitive reactance.

- The following data is loaded into the memory register prior to running the program:

	R_0	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
	—	T_0	B	R_{25}	X	—	C_0	f_s	r	—
Units		$^{\circ}\text{C}$	$^{\circ}\text{K}$	Ω	Ω		Farad	H_z	Numeric	

$$\text{wh} \quad X_0 = \frac{1}{\omega_s C_0}$$

N. B.

X entered in R_4 is a negative quantity!

- T in $^{\circ}\text{C}$ is entered in the display before running the program.
 - At completion, the program displays $\Delta f/f$ and also stores $\Delta f/f$ in R_9
-

Some miscellaneous notes on the program:

- The program has NOP for steps 00 and 01. If these steps are keyed RCL 0 then T can be stored in R_0 prior to running prog.
- Steps 30 and 51 are also NOP. If R/S is entered in 30 and 51 the program will stop and display

$$\frac{R_T}{R_{25}} = E^B \left(-\frac{1}{T} - \frac{1}{T_0} \right)$$

at step 30 and X_t at step 51. Thus, the intermediate results in calculating $\Delta f/f_s$ are available.

- R_5 is used during the program to store X_t .

TEST PROBLEM

R_0	R_1	R_4	R_3		R_5	R_6	R_7	R_8	R_9
—	25	3000	30	-300	—	3.5×10^{-12}	50×10^6	2200	

$T (^{\circ}C)$	$\frac{\Delta f}{f}$ (PPM)
- 40	- 44.196
- 30	- 31.426
- 20	- 18.164
- 10	- 9.127
0	- 4.361
10	- 2.095
20	- 1.037
30	- 0.532
40	- 0.284
45	- 0.210

PROGRAM #2

CRYSTAL COMPENSATION USING THERMISTOR/ CAPACITOR NETWORK

- This program is very similar to program #1. Steps 02 to 76 are identical for programs 1 and 2. The purpose of program 2 is given $\frac{\Delta f}{f} /_{t=t_1}$. The program searches for a value of X which satisfies $\frac{\Delta f}{f} /_{t=t_1}$. Once this value of X is obtained the program can be easily changed to program #1 for calculation of $\frac{\Delta f}{f}$ at various temperatures. Each time program is iterated the computed $\frac{\Delta f}{f}$ is displayed (Step 77).
- The storage registers must be loaded as follows before running the program:

R_T	R_0	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
$\frac{\Delta f}{f} /_{t_1}$	$\frac{1}{10} \Delta X$	T_0 °C	β °K	R_{25}	X	—	C_0 Farad	f_s Hz	r	t_1

X is negative and is a guess at the maximum reactance required. ΔX is the increment by which X changes during the program. ΔX is entered in steps 89 and 90 of the program. The program computes X_i (the value of X used in a particular calculation) as $(1/10) R_0 (\Delta X) = X_i$. R_0 is decremented each time program cycles.

For example:

$X = -200$ Steps 89 and 90 $\Delta X = 10$
as shown in program

$$R_0 - \frac{X}{10} = 20$$

Prog. iteration	Value X_i
1	200
2	190
3	180
.	.
.	.
.	.

- t_1 is the temperature for which the calculation is done. $\frac{\Delta f}{f} / t_1$ is the value of $\frac{\Delta f}{f} / t_1$ is the value of $\frac{\Delta f}{f}$ at t_1 for which the program calculates X .
- To run the program press RST then R/S
- At program completion the display is the value of $\frac{\Delta f}{f}$ @ which calculation stopped. R_4 contains the required value of X to yield the displayed value of $\frac{\Delta f}{f_s} / t_1$

PAGE _____ OF _____

DATE 11-22-2011

SR-56 Coding Form

TEXAS INSTRUMENTS
INCORPORATED



LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
00	34	RCL		25	64	X		50	05	5		75	94	=	
01	09	9		26	34	RCL		51	46	NOP		76	20	1/X	
02	84	+		27	02	2		52	74	—		77	59	PAUSE	
03	02	2		28	94	=		53	52	(		78	12	INV	
04	07	7		29	14	E ^x		54	34	RCL		79	47	X ≥ t	
05	03	3		30	46	NOP		55	06	6		80	09	9	
06	92	•		31	64	X		56	64	X		81	09	9	
07	01	1		32	34	RCL		57	34	RCL		82	12	INV	
08	08	8		33	03	3		58	07	7		83	27	dsz	
09	94	=		34	94	=		59	64	X		84	09	9	
10	20	1/X		35	54	÷		60	02	2		85	08	8	
11	74	—		36	34	RCL		61	64	X		86	34	RCL	
12	52	(		37	04	4		62	69	π		87	00	0	
13	34	RCL		38	94	=		63	53	)		88	64	X	
14	01	1		39	20	1/X		64	20	1/X		89	01	1	
15	84	+		40	43	X ²		65	94	=		90	00	0	
16	02	2		41	84	+		66	64	X		91	93	+/-	
17	07	7		42	01	1		67	34	RCL		92	94	=	
18	03	3		43	94	=		68	08	8		93	33	STO	
19	92	•		44	54	÷		69	64	X		94	04	4	
20	01	1		45	34	RCL		70	02	2		95	22	GTO	
21	08	8		46	04	4		71	94	=		96	00	0	
22	53	)		47	94	=		72	54	÷		97	00	0	
23	20	1/X		48	20	1/X		73	34	RCL		98	03	3	
24	94	=		49	33	STO		74	05	5		99	41	R/S	

REGISTERS	
0	
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[illegible]

TEST PROBLEM

$$1. \quad \Delta X = 10 \quad X = -200 \quad \frac{\Delta f}{f} \bigg|_{-40} = 15 \times 10^{-6}$$

$$t_1 = -40^{\circ}\text{C} \quad R_{25} = 10 \, \Omega \quad C_0 = 3.5 \, \text{Pf} \quad f_s = 50 \times 10^6$$

$$r = 2200$$

R_T	R_0	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
15×10^{-6}	20	25	3000	10	-200	—		3.5×10^{12}	50×10^6	-40

Step 89 1 ΔX
90 0

At program completion:

DISPLAY: 0.0000139218
R₄ : -70
R₀ : 7

$$2. \quad \Delta X = 5 \quad X = -120 \quad \text{All other parameters}$$

as in problem #1

R_0	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
24	25	3000	10	-120	—	3.5×10^{-12}	50×10^6	2200	-40

$$R_T$$

$$15 \times 10^{-6}$$

Step 89 5
90 NOP

At program completion:

DISPLAY: 0.000014545
R₄ : -75
R₀ : 15

3. $\Delta X = 1$ $X = -100$ All other parameters

As in problem #1

R_0	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
100	25	3000	10	-100	—	3.5×10^{-12}	50×10^6	2200

R_9	R_T		Step	89	1
-40	15×10^{-6}			90	NOP

At program completion:

DISPLAY:		0.0000148943
R_4	:	-78
R_0	:	78

PROGRAM #3

CRYSTAL COMPENSATION USING THERMISTOR/ CAPACITOR NETWORK

- The basis for this program is program #1. Steps 19 thru 87 of this program are similar to steps 02 thru 80 of program 1. The only differences are that 273.18 $\rightarrow$ 273 in program 3, and the four NOP steps and steps 77, 78 of program 1, are eliminated. Steps 00 to 18 of this program produce values of $T^{\circ}\text{C}$ from +50 to -40°C stepping through the temperature range in 10°C steps for each program iteration.
- The registers are loaded prior to running program exactly as in program #1.
- The program is run by loading the registers, pressing RST, and then R/S. The program then computes $\Delta f/f$ for the parameters in the register in 10°C intervals from -40°C to $+50^{\circ}\text{C}$. A short time after pressing R/S the temp for which the calculation is being done is displayed for ≈ 1 sec., then the program continues and computes $\Delta f/f$ and displays the result for ≈ 4 sec before continuing the calculation at the next temperature.

TEST PROBLEM

R_0	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
—	25	3000	30	-300	—	3.5×10^{-12}	50×10^6	2200	—

<u>T (°C)</u>	<u>$\Delta f/f$ (PPM)</u>
- 40	44.269
- 30	31.512
- 20	18.222
- 10	9.1539
0	4.371
10	2.098
20	1.037
30	0.5326
40	0.0284
50	0.015

TITLE CRYSTAL COMP #3 PAGE OF

PROGRAMMER _____ DATE _____

SR-56 Coding Form

TEXAS INSTRUMENTS
INCORPORATED



LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
00		1		25		—		50		X ²		75		X	
01		1		26		(		51		+		76		RCL	
02		STO		27		RCL		52		1		77		8	
03		0		28		1		53		=		78		X	
04		INV		29		+		54		÷		79		2	
05		dsz		30		2		55		RCL		80		=	
06		9		31		7		56		4		81		÷	
07		8		32		3		57		=		82		RCL	
08		RCL		33		)		58		1/X		83		5	
09		0		34		1/X		59		STO		84		=	
10		X		35		=		60		5		85		1/X	
11		1		36		X		61		—		86		EE	
12		0		37		RCL		62		(		87		=	
13		—		38		2		63		RCL		88		PAU	
14		5		39		=		64		6		89		PAU	
15		0		40		E ^x		65		X		90		PAU	
16		=		41		X		66		RCL		91		PAU	
17		PAUSE		42		RCL		67		7		92		PAU	
18		PAUSE		43		3		68		X		93		PAU	
19		+		44		=		69		2		94		PAU	
20		2		45		÷		70		X		95		GTO	
21		7		46		RCL		71		π		96		0	
22		3		47		4		72		)		97		4	
23		=		48		=		73		1/X		98		R/S	
24		1/X		49		1/X		74		=		99		RST	

REGISTERS	
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[illegible]

PROGRAM #4

CRYSTAL COMPENSATION USING THERMISTOR/ CAPACITOR NETWORK

This program solves the eqn:

$$R_t = \frac{X^2 R_T}{R_T^2 + X^2}$$

When memories are loaded and R/S pressed, the program runs the calculation for R_t for $-40 \leq t \leq 50^\circ\text{C}$ in 10°C increments automatically. As each calculation is made the temperature is displayed. Then after a few seconds R_t for that temperature is displayed for approximately 5 seconds.

Steps 00 through 44 of this program are identical to those of program #3.

Before running the program the four memory registers, R_1 , R_2 , R_3 , R_4 , must be loaded exactly as they were in program #1.

TEST PROBLEM

R_1	R_2	R_3	R_4
25	3000	14	-288

<u>Temp.</u>	<u>$R_t (\Omega)$</u>
50	6.419
40	8.633
30	11.837
20	16.568
10	23.707
0	34.678
-10	51.672
-20	77.338
-30	111.55
-40	140.72

PROGRAMMER _____ DATE _____

TEXAS INSTRUMENTS
INCORPORATED



LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
00		1		25		—		50		4		75		R/S	
01		1		26		(		51		X ²		76		RST	
02		STO		27		RCL		52		=		77			
03		0		28		1		53		1/X		78			
04		INV		29		+		54		X		79			
05		dsz		30		2		55		RCL		80			
06		7		31		7		56		4		81			
07		5		32		3		57		X ²		82			
08		RCL		33		)		58		X		83			
09		0		34		1/X		59		RCL		84			
10		X		35		=		60		5		85			
11		1		36		X		61		=		86			
12		0		37		RCL		62		PAU		87			
13		—		38		2		63		PAU		88			
14		5		39		=		64		PAU		89			
15		0		40		E ^x		65		PAU		90			
16		=		41		X		66		PAU		91			
17		PAU		42		RCL		67		PAU		92			
18		PAU		43		3		68		PAU		93			
19		+		44		=		69		PAU		94			
20		2		45		STO		70		PAU		95			
21		7		46		5		71		PAU		96			
22		3		47		X ²		72		GTO		97			
23		=		48		+		73		0		98			
24		1/X		49		RCL		74		4		99			

REGISTERS	
0	USED
1	$T_o (^{\circ}\text{C})$
2	$B (^{\circ}\text{K})$
3	$R_{25} (\Omega)$
4	$X (\Omega)$
5	
6	
7	
8	
9	

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APPENDIX II

RF AMPLIFIER CHARACTERISTICS

Amperex

REPRODUCIBILITY OF THE TYPES

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BGY22, BGY22A

HYBRID
INTEGRATED CIRCUITS

ADVANCE DATA

UHF BROADBAND POWER AMPLIFIER MODULE

2.5W • 380 to 512 MHz • 12.5V

- OUTPUT POWER : 2.5 W @ 380 to 512 MHz
- HARMONIC CONTENT 20 dB DOWN FROM CARRIER
- CHARACTERIZED WITH RF SOAR CURVES
- RUGGEDIZED AGAINST MISMATCH FAILURES

The Amperex types BGY22 and BGY22A are broadband UHF amplifier modules primarily designed for mobile communications equipment operating directly from 12 V vehicle electrical systems.

Each module consists of a two stage RF amplifier using NPN transistor chips, together with lumped element matching components

The BGY22 will produce 2.5 W output into a 50 Ω load over the band 380 to 512 MHz

The BGY22A will produce 2.5 W output into a 50 Ω load over the band 420 to 480 MHz.

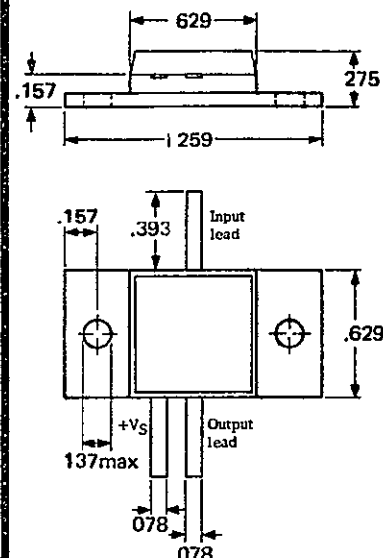
The modules are designed to withstand full load mismatch under the following conditions:

$V_s = 16.5V$, $P_s = P_s(\text{nom}) + 20\%$, $T_{hs} = 70^\circ C$, $VSWR = 50:1$ through all phases, where

$P_s(\text{nom}) = P_s$ for 2.5 W module output under nominal conditions

ABSOLUTE MAXIMUM RATINGS

	SYMBOL	VALUE
Supply Voltage	V_s	18 V
D.C. supply terminal to flange		
Input Voltage	$\pm V_i$	25 V
Input terminal to flange		
Output Voltage	$\pm V_o$	25 V
Output terminal to flange		
Supply Current, d.c.	I_T	800 mA
Input Source Power	P_s	150 mW
$V_s = 13.5V$, $Z_L = 50 \Omega$		
Storage Temperature	$T_{stg.}$	-40 to + 100°C
Operating Heatsink Temperature	T_{hs}	90°C



OUTLINE DRAWING

October, 1972

Amperex

BGY22, BGY22A

ELECTRICAL CHARACTERISTICS ($T_{hs} = 25^{\circ}\text{C}$ unless otherwise noted)
Reference planes at RF input and output terminals are .039" from the plastic encapsulation.

	SYMBOL	MIN	TYP	MAX	UNITS
Quiescent Current $V_s = 13.5\text{ V}, P_s = 0$	I_{SQ}	4	7	12	mA
Load Power $V_s = 13.5\text{ V}, P_s = 50\text{ mW}$	P_L	2.5	2.9	3.5	W
Efficiency $V_s = 13.5\text{ V}, P_s = 50\text{ mW}$	η	40	50	—	%
Harmonic Content		any harmonic is at least 20 dB down relative to carrier.			
Input VSWR with respect to 50 Ω		—	—	2:1	
Stability $V_s = 10.5\text{ to }15.0\text{ V}, P_s = 10\text{ to }100\text{ mW},$ $T_{hs} = -40\text{ to }+90^{\circ}\text{C}$					
output load VSWR $\leq 3:1$ through all phases		no instabilities			
output load VSWR $\leq 10:1$ through all phases		no appreciable instabilities			

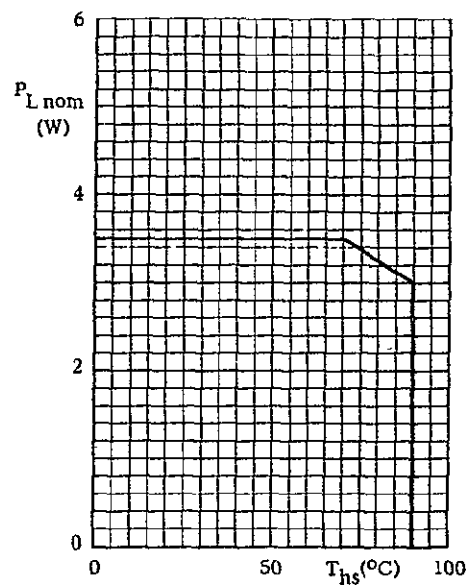


Figure 1 Nominal Load Power vs. Heatsink Temperature

APPLICATION INFORMATION

REPRODUCIBILITY OF THE
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BGY22, BGY22A

RF performance in CW operation, $T_{hs} = 25^\circ\text{C}$

Drive source and load impedance $Z_S = Z_L = 50\ \Omega$

f (MHz)	V_S (V)	P_S (mW)	P_L (W)	η (%)	
380 to 512	13.5	< 50	2.5	> 40	} <u>BGY22</u>
380 to 512	13.5	typ. 50	2.9	typ. 50	
380 to 512	12.5	typ. 50	2.5	—	
380 to 512	15.0	typ. 50	3.6	—	
420 to 480	12.5	< 50	2.5	> 40	<u>BGY22A</u>

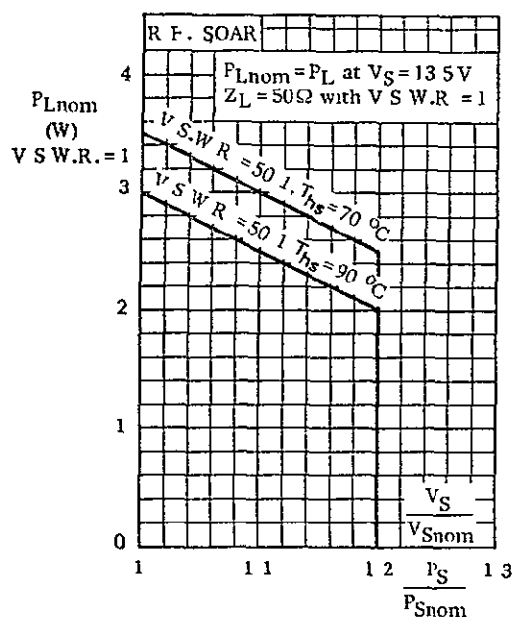


Figure 2 RF Safe Operating Area

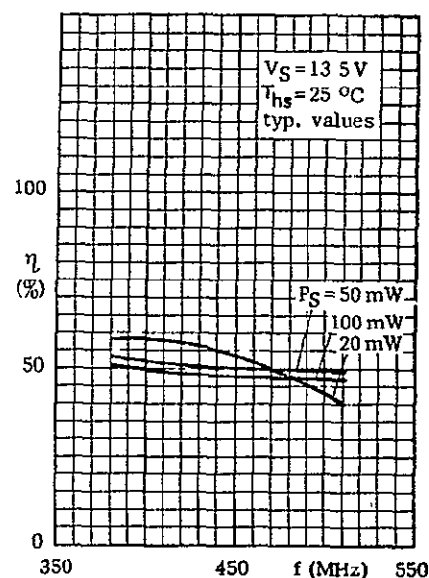


Figure 3 Efficiency vs. Frequency

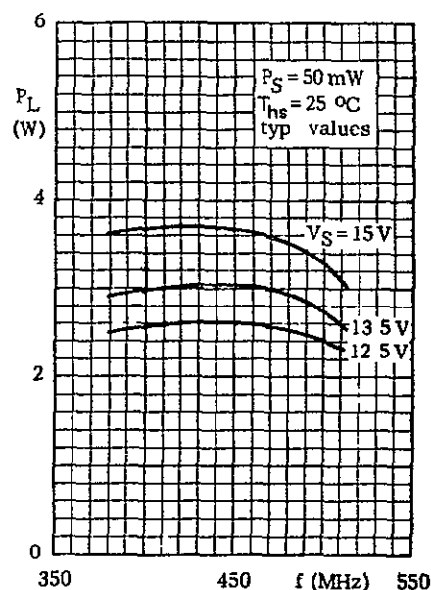
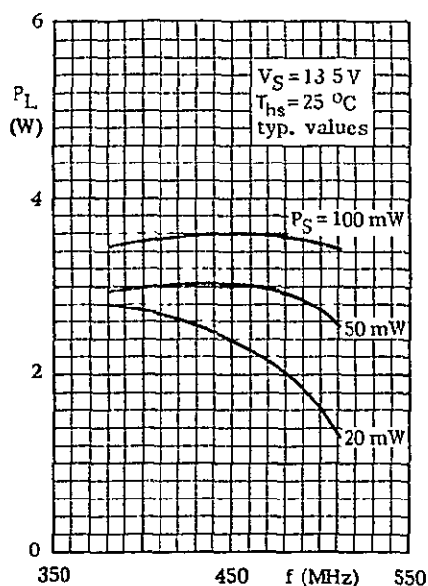


Figure 4,5 Load Power vs. Frequency

Amperex® ... Tomorrow's Thinking in Today's Products®

APPENDIX III
ELECTRICAL PARTS LIST



PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE MDCP1										SCHEMATIC DWG NO					
ORIGINATOR				DATE		APPROVED E E			DATE		APPROVED M E			DATE	
QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION			PAD DIA	HOLE DIA
504	503	502	501								COMPONENT				
											A	B	C		
				R1	RCR05G181JS	180Ω 1/8w									
				R2	RCR05G123JS	12K 1/8w									
				R3	RCR05G123JS	12K 1/8w									
				R4	RCR05G472JS	4.7K 1/8w									
				R5	RCR05G101JS	100 Ω 1/8w									
				R6	RCR05G222JS	2.2K 1/8w									
				R7	RCR05G681JS	680 Ω 1/8w									
				R8	RCR05G123JS	12K 1/8w									
				R9	RCR05G123JS	12K 1/8w									
				R10	RCR05G101JS	100 Ω 1/8w									
				R11	RCR05G180JS	180 Ω 1/8w									
				R12	RCR05G102JS	1K 1/8w									
				R13	RCR05G123JS	12K 1/8w									
				R14	RCR05G123JS	12K 1/8w									
				R15	RCR05G101JS	100 Ω 1/8w									
				R16	RCR05G681JS	680 Ω 1/8w									
				R17	RCR05G271JS	270 Ω 1/8w									
				R18	RCR05G180JS	18 Ω 1/8w									
				R19	RCR05G271JS	270 Ω 1/8w									
				R20	RCR05G123JS	12K 1/8w									
				R21	RCR05G101JS	100 Ω 1/8w									
				R22	RCR05G101JS	100 Ω 1/8w									
				R23	RCR05G270JS	270 Ω 1/8w									
				R24	RCR05G180JS	18 Ω 1/8w									
				R25	RCR05G271JS	270 Ω 1/8w									
				R26	RCR05G473JS	47K 1/8w									

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR



PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE MDCP1				SCHEMATIC DWG NO							
ORIGINATOR		DATE		APPROVED E E		DATE		APPROVED M E		DATE	

QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION				
504	503	502	501								COMPONENT			PAD DIA	HOLE DIA
				R27	RCR05G123JS	12K 1/8w									
				R28	RCR05G101JS	100 Ω 1/8w									
				R29	RCR05G101JS	100 Ω 1/8w									
				R30	RCR05G472JS	4.7K 1/8w									
				R31	RCR05G472JS	4.7K 1/8w									
				R32	RCR05G102JS	1K 1/8w									
				R33	RCR05G472JS	4.7K 1/8w									
				R34	RCR05G102JS	1K 1/8w									
				R35	RCR05G332JS	3.3K 1/8w									
				R36	RCR05G221JS	220 Ω 1/8w									
				R37	RCR05G220JS	22 Ω 1/8w									
				R38	RCR05G221JS	220 Ω 1/8w									
				R39	RCR05G332JS	3.3K 1/8w									
				R40	RCR05G332JS	3.3K 1/8w									
				R41	RCR05G332JS	3.3K 1/8w									
				R42	RCR05G332JS	3.3K 1/8w									
				R43	RCR05G332JS	3.3K 1/8w									
				R44	RCR05G332JS	3.3K 1/8w									
				R45	RCR05G221JS	220 Ω 1/8w									
				R46	RCR05G220JS	22 Ω 1/8w									
				R47	RCR05G221JS	220 Ω 1/8w									
				R48	RCR05G222JS	2.2K 1/8w									
				R49	RCR05G821JS	820 Ω 1/8w									
				R50	RCR05G101JS	100 Ω 1/8w									
				R51	RCR05G101JS	100 Ω 1/8w									
				R61	RCR07G332JS	3.3K 1/4w									

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR



PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE		MDCPI		SCHEMATIC DWG NO											
ORIGINATOR		DATE		APPROVED E E		DATE		APPROVED M E		DATE					
QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION				
504	503	502	501								COMPONENT			PAD DIA	HOLE DIA
											A	B	C		
				Q1	JAN 2N2857	Transistor				Motorola					
				Q2	JAN 2N2857	Transistor				Motorola					
				Q3	JAN 2N2857	Transistor				Motorola					
				Q4	JAN 2N2857	Transistor				Motorola					
				Q5	JAN 2N2857	Transistor				Motorola					
				Q6	JAN 2N2857	Transistor				Motorola					
				Q7	JAN 2N2222A	Transistor									
				Q8	JAN 2N3244	Transistor									
				Q9	JAN 2N2222A	Transistor									
				Q12	DHE-3	Transistor				CTC					
				Q13	DM5-128A	Transistor				CTC					
				U1		Thermistor									
				U2	XTAL										
				L1	SW-W-1.0	1 μ h				Nytronics					
				L2	SW-W-0.47	.47 μ h				Nytronics					
				L3	SW-W-0.68	.68 μ h				Nytronics					
				L4	SW-W-0.68	.68 μ h				Nytronics					
				L5	SW-W-0.47	.47 μ h				Nytronics					
				L6	AEL	3 $\frac{1}{2}$ T 1/8" ID #18									
				L7	AEL	2 $\frac{1}{2}$ T 1/8" ID #18									
				L8	AEL	1 $\frac{1}{2}$ T 1/8" ID #18									
				L9	AEL	UT 34 $\approx$ 3"									

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PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE MDCP1				SCHEMATIC DWG NO					
ORIGINATOR		DATE	APPROVED E E		DATE	APPROVED M E		DATE	

QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION				
504	503	502	501								COMPONENT			PAD DIA	HOLE DIA
				L10	AEL	UT 34 $\approx$ 6"									
				L11	AEL	1 $\frac{1}{2}$ T 1/8" ID #18									
				L12	AEL	$\frac{1}{2}$ T 1" #18									
				L13	AEL	$\frac{1}{2}$ T 2" #18									
				L14	AEL	$\frac{1}{2}$ T 1" #18									
				L15	AEL	$\frac{1}{2}$ T 1" #18									
				RFC1	56-590-65/4B	RF Bead									
				RFC2	56-590-65/4B	RF Bead									
				RFC3	56-590-65/4B	RF Bead									
				RFC4	56-590-65/4B	RF Bead									
				VR1	GLA62	Zener									
				VR2	1N 757	Zener									
				CR1	HP5082-3039	Diode				HP					
				CR2	HP5082-3039	Diode				HP					
				CR3	HP5082-3039	Diode				HP					
				CR4	HP5082-3039	Diode				HP					
				CR5	HP5082-3039	Diode				HP					
				CR6	HP5082-3039	Diode				HP					
				CR7	JAN1N4454	Diode									
				CR8	JAN1N4454	Diode									



PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE MDCP1				SCHEMATIC DWG NO				
ORIGINATOR		DATE	APPROVED EE		DATE	APPROVED ME		DATE

QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION				
504	503	502	501								COMPONENT			PAD DIA	HOLE DIA
											A	B	C		
				C1	3BN0505270J	27 pf									
				C2	3BN0505101J	100									
				C3	3BN0505102J	1K									
				C4	3BN0505102J	1K									
				C5	5871 Johanson	.5 — 7									
				C6	3BN0505101J	100 pf									
				C7	3BN0505102J	1K									
				C8	3BN0505102J	1K									
				C9	5871 Johanson	.5 — 7									
				C10	3BN0505220J	22 pf									
				C11	3BN0505102J	1K									
				C12	3BN0505102J	1K									
				C13	5871 Johanson	.5 — 7									
				C14	3BN0505220J	22 pf									
				C15	5871 Johanson	.5 — 7									
				C16	5871 Johanson	.5 — 7									
				C17	3BN0505121J	120									
				C18	3BN0505102J	1K									
				C19	3BN0505102J	1K									
				C20	5871 Johanson	.5 — 7									
				C21	5871 Johanson	.5 — 7									
				C22	5871 Johanson	.5 — 7									
				C23	5871 Johanson	.5 — 7									
				C24	3BN0505121J	120 pf									
				C25	3BN0505471J	470 pf									
				C26	3BN0505471J	470 pf									



PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE				MDCP1				SCHEMATIC DWG NO			
ORIGINATOR		DATE		APPROVED E E		DATE		APPROVED M E		DATE	

QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION				
504	503	502	501								COMPONENT			PAD DIA	HOLE DIA
											A	B	C		
				C70	ATC100B201KC300	200 pf									
				C71	ATC100B201KC300	200 pf									
				C72	ATC100B150DC500	15									
				C73	ATC100B300DC500	30									
				C74	ATC100B6R2DC500	6.2									
				C75	ATC100B6R2DC500	6.2									
				C76	ATC100B4R7DC500	4.7									
				C77	ATC100B201KC300	200									
				C78	ATC100B201KC300	200									
				C79											
				C80	ATC100B101KC300	100									
				C81	ATC100B101KC300	100									
				C82	ATC100B101KC300	100									
				C83	ATC100B220DC500	22									
				C84	ATC100B220DC500	22									
				C85	ATC100 B101KC500	100									
				C86	ATC100B201KC300	200									
				C87	ATC100B201KC300	200									
				C88	ATC100B100 DC500	10									
				C89	ATC200B100DC500	10									
				C90	ATC100B100DC500	10									
				C91	ATC100B150DC500	15									
				C92	ATC100B220DC500	22									



PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE		MDCP2		SCHEMATIC DWG NO	
ORIGINATOR	DATE	APPROVED E E	DATE	APPROVED M E	DATE

QTY REQ'D					ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION				
504	503	502	501									COMPONENT			PAD DIA	HOLE DIA
					R1	RCR05G820JS	82 Ω 1/8w $\pm$ 5%									
					R2	RCR05G123JS	12K									
					R3	RCR05G123JS	12K									
					R4	RCR05G222JS	2.2K									
					R5	RCR05G101JS	100 Ω									
					R6	RCR05G101JS	100 Ω									
					R7	RCR05G680JS	68 Ω									
					R8	RCR05G101JS	100 Ω									
					R9	RCR05G560JS	5.6 Ω									
					R10	RCR05G123JS	12K									
					R11	RCR05G222JS	2.2K									
					R12	RCR05G681JS	680 Ω									
					R13	RCR05G101JS	100 Ω									
					R14	RCR05G182JS	1.8K									
					R15	RCR05G183JS	18K									
					R16	RCR05G183JS	18K									
					R17	RCR05G121JS	120 Ω									
					R18	RCR05G271JS	270 Ω									
					R19	RCR05G180JS	18 Ω									
					R20	RCR05G271JS	270 Ω									
					R21	RCR05G101JS	100 Ω									
					R22	RCR05G472JS	4.7K 1/8w $\pm$ 5%									
					R23	RCR05G102JS	1.0K 1/8w $\pm$ 5%									
					R24	RCR05G200JS	20 Ω									
					R25	RCR05G200 JS	20 Ω									
					R26	RCR05G102JS	1K									

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PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE										SCHEMATIC DWG NO																			
ORIGINATOR					DATE					APPROVED E E					DATE					APPROVED M E					DATE				
QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION			PAD DIA	HOLE DIA														
504	503	502	501								COMPONENT																		
				R27	RCR05G472JS	4K																							
				R28	RCR05G472JS	4.7K																							
				R29	RCR05G221JS	220 Ω																							
				R30	RCR05G220JS	22 Ω																							
				R31	RCR05G221JS	220 Ω																							
				R32	RCR05G332JS	3.3K																							
				R33	RCR05G332JS	3.3K																							
				R34	RCR05G332JS	3.3K																							
				R35	RCR05G332JS	3.3K																							
				R36	RCR05G332JS	3.3K																							
				R37	RCR05G332JS	3.3K																							
				R38	RCR05G221JS	220 Ω																							
				R39	RCR05G220J	22 Ω																							
				R40	RCR05G220JS	220 Ω																							
				R41	RCR05G100JS	10 Ω																							
				R42	RCR05G151JS	150 Ω																							
				R43	RCR05G330JS	33 Ω																							
				R44	RCR05G150 JS	150 Ω																							
				R45	RCR05G280JS	28 Ω																							
				R46	RCR05G432JS	4.3K																							
				R47	RCR05G102JS	1K																							
				R48	RCR05G101JS	100 Ω																							
				R49	RCR05G201JS	200 Ω																							
				R50	RCR05G101JS	100 Ω																							
				R51	RCR05G102JS	1K																							



PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE				MDCP2				SCHEMATIC DWG NO			
ORIGINATOR		DATE		APPROVED E E		DATE		APPROVED M E		DATE	

QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION				
504	503	502	501								COMPONENT			PAD DIA	HOLE DIA
				C1	3BN0505202J	2K pf 50V $\pm 5\%$ chip									
				C2	3BN0505101J	100 pf 50V $\pm 5\%$ chip									
				C3	3BN0505270J	27 pf 50V $\pm 5\%$ chip									
				C4	3BN0505202J	2K pf 50V $\pm 5\%$ chip									
				C5	3BN05055201	.8-10 pf Variable									
				C6	CMO5 101	100 pf Mila									
				C7	CMO5 101	100 pf Mila									
				C8	3BN0505202J	2K pf 50V $\pm 5\%$ chip									
				C9	3BN0505202J	2K pf 50V $\pm 5\%$ chip									
				C10	3BN0505202J	2K pf 50V $\pm 5\%$ chip									
				C11	3BN0505102J	1K pf 50V $\pm 5\%$ chip									
				C12	3BN05055201	.8-10 pf Variable									
				C13	3BN0505220J	22 pf 50V $\pm 5\%$ chip									
				C14	3BN0505202J	2K 50V $\pm 5\%$ chip									
				C15	3BN05051R0J	1 pf 50V $\pm 5\%$ chip									
				C16	3BN05055201	.8-10 pf Variable									
				C17	3BN05051R0J	1 pf 50V $\pm 5\%$ Chip									
				C18	3BN05055201	.8-10pf Variable									
				C19	3BN05051R0J	1 pf 50V $\pm 5\%$ Chip									
				C20	3BN05055201	.8-10 pf Variable									
				C21	3BN05051R0J	1 pf 50V $\pm 5\%$ Chip									
				C22	3BN0505471J	470 pf 50V $\pm 5\%$ chip									
				C24	3BN05051R0J	1 pf 50V $\pm 5\%$ chip									
				C25	3BN0505471J	470 pf 50V $\pm 5\%$ chip									
				C26	3BN0505471J	470 pf 50V $\pm 5\%$ Chip									



PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE										SCHEMATIC DWG NO								
ORIGINATOR				DATE		APPROVED E E			DATE		APPROVED M E			DATE				
DESCRIPTION				VALUE		TOL		RATING		SPECIFICATION OR VENDOR		DESIGNER'S INFORMATION						
												COMPONENT			PAD DIA		HOLE DIA	
												A	B	C				
470 pf 50V <u>+5%</u> chip																		
470 pf 50V <u>+5%</u> chip																		
470 pf 50V <u>+5%</u> chip																		
470 pf 50V <u>+5%</u> chip																		
470 pf 50V <u>+5%</u> chip																		
470 pf 50V <u>+5%</u> chip																		
470 pf 50V <u>+5%</u> chip																		
470 pf 50V <u>+5%</u> chip																		
470 pf 50V <u>+5%</u> chip																		
470 pf 50V <u>+5%</u> chip																		
470 pf 50V <u>+5%</u> chip																		
470 pf 50V <u>+5%</u> chip																		
470 pf 50V <u>+5%</u> chip																		
.8-10 pf Variable																		
470 pf 50V <u>+5%</u> chip																		
2000pf <u>+5%</u> chip																		
2000pf <u>+5%</u> chip																		
2000pf <u>+5%</u> chip																		
2000pf <u>+5%</u> chip																		
2000pf <u>+5%</u> chip																		
2000pf <u>+5%</u> chip																		
1-30 pf Variable																		
Electrolytic 1.5 μ f																		
Electrolytic 1.5 μ f																		
1000 pf <u>+5%</u> chip																		
Electrolytic 1.5 μ f																		



SCHEMATIC TITLE				SCHEMATIC DWG NO			
MDCP2							
ORIGINATOR	DATE	APPROVED EE	DATE	APPROVED ME	DATE		

[illegible]

[illegible]



PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE MDCP3				SCHEMATIC DWG NO					
ORIGINATOR		DATE	APPROVED E E		DATE	APPROVED M E		DATE	

QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION				
504	503	502	501								COMPONENT			PAD DIA	HOLE DIA
											A	B	C		
				R1	RCR05G181JS	180 Ω 1/8w									
				R2	RCR05G123JS	12K									
				R3	RCR05G123JS	12K									
				R4	RCR05G472JS	4.7K									
				R5	RCR05G101JS	100 Ω									
				R6	RCR05G222JS	2.2K									
				R7	RCR05G681JS	680 Ω									
				R8	RCR05G123JS	12K									
				R9	RCR05G123JS	12K									
				R10	RCR05G101JS	100 Ω									
				R11	RCR05G181JS	180 Ω									
				R12	RCR05G102JS	1K									
				R13	RCR05G123JS	12K									
				R14	RCR05G123JS	12K									
				R15	RCR05G101JS	100 Ω									
				R16	RCR05G681JS	680 Ω									
				R17	RCR05G271JS	270 Ω									
				R18	RCR05G180JS	18 Ω									
				R19	RCR05G271JS	270 Ω									
				R20	RCR05G123JS	12K									
				R21	RCR05G101JS	100 Ω									
				R22	RCR05G101JS	100 Ω									
				R23	RCR05G271JS	270 Ω									
				R24	RCR05G180JS	18 Ω									
				R25	RCR05G271JS	270 Ω									
				R26	RCR05G472JS	4.7K									

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PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE		MDCP3		SCHEMATIC DWG NO	
ORIGINATOR	DATE	APPROVED E E	DATE	APPROVED M E	DATE

QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION				
504	503	502	501								COMPONENT			PAD DIA	HOLE DIA
											A	B	C		
				R27	RCR05G123JS	12K									
				R28	RCR05G101JS	100 Ω									
				R29	RCR05G101JS	100 Ω									
				R30	RCR05G472JS	4.7K									
				R31	RCR05G472JS	4.7K									
				R32	RCR05G102JS	1K									
				R33	RCR05G472JS	4.7K									
				R34	RCR05G102JS	1K									
				R35	RCR05G332JS	3.3K									
				R36	RCR05G221JS	220 Ω									
				R37	RCR05G220JS	22 Ω									
				R38	RCR05G221JS	220 Ω									
				R39	RCR05G332JS	3.3K									
				R40	RCR05G332JS	3.3K									
				R41	RCR05G332JS	3.3K									
				R42	RCR05G332JS	3.3K									
				R43	RCR05G332JS	3.3K									
				R44	RCR05G332JS	3.3K									
				R45	RCR05G221JS	220 Ω									
				R46	RCR05G220JS	22 Ω									
				R47	RCR05G221JS	220 Ω									
				R48	RCR05G222JS	220 Ω									
				R49	RCR05G821JS	820 Ω									
				R50	RCR05G101JS	100 Ω									
				R51	RCR05G101JS	100 Ω									
				R52	RCR05G821JS	820 Ω									



PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE				MDCP8				SCHEMATIC DWG NO			
ORIGINATOR		DATE		APPROVED E E		DATE		APPROVED M E		DATE	

QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION				
504	503	502	501								COMPONENT			PAD DIA	HOLE DIA
											A	B	C		
				C1	3BN0505270J	27 pf									
				C2	3BN0505101J	100									
				C3	3BN0505102J	1K									
				C4	3BN0505102J	1K									
				C5	5851 Johanson	.5 — 7									
				C6	3BN0505101J	100 pf									
				C7	3BN0505102J	1K									
				C8	3BN0505102J	1K									
				C9	5851 Johanson	.5 — 7									
				C10	3BN0505220J	22 pf									
				C11	3BN0505102J	1K									
				C12	3BN0505102J	1K									
			✓	C13	5851 Johanson	.5 — 7									
				C14	3BN0505220J	22 pf									
			✓	C15	5851 Johanson	.5 — 7									
				C16	5851 Johanson	.5 — 7									
				C17	3BN0505121J	120									
				C18	3BN0505102J	1K									
				C19	3BN0505102J	1K									
			-	C20	5851 Johanson	.5 — 7									
				C21	5851 Johanson	.5 — 7									
				C22	5851 Johanson	.5 — 7									
			✓	C23	5851 Johanson	.5 — 7									
				C24	3BN0505121J	120 pf									
				C25	3BN0505471J	470 pf									
				C26	3BN0505471J	470 pf									



QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION				
504	503	502	501								COMPONENT			PAD DIA	HOLE DIA
											A	B	C		
			✓	C27	5851 Johanson	.5 — 7 pf									
			✓	C28	5851 Johanson	.5 — 7 pf									
				C29	M39003/01-2280	1.5 μf									
			✓	C30	M39003/01-2280	1.5 μf									
				C31	3BN0505471J	470 pf									
				C32	3BN0505471J	470 pf									
				C33	3BN0505471J	470 pf									
				C34	3BN0505471J	470 pf									
				C35	3BN0505471J	470 pf									
				C36	3BN0505471J	470 pf									
				C37	3BN0505471J	470 pf									
				C38	3BN0505471J	470 pf									
				C39	3BN0505471J	470 pf									
				C40	3BN0505471J	470 pf									
				C41	3BN0505471J	470 pf									
			✓	C42	5851 Johanson	.5 — 7 pf									
			✓	C43	5851 Johanson	.5 — 7 pf									
				C44	3BN0505471J	470 pf									
				C45	3BN0505471J	470 pf									
				C46											
				C47											
				C48	3BN0505471J	470 pf									
				C49											



PRELIMINARY PARTS LIST (ELECTRICAL)

SCHEMATIC TITLE				MDCP3				SCHEMATIC DWG NO			
ORIGINATOR		DATE		APPROVED EE		DATE		APPROVED ME		DATE	

QTY REQ'D				ITEM OR SYMBOL	PART NO	DESCRIPTION	VALUE	TOL	RATING	SPECIFICATION OR VENDOR	DESIGNER'S INFORMATION				
504	503	502	501								COMPONENT			PAD DIA	HOLE DIA
											A	B	C		
				L1	SW-W-1.0	1 μ h									
				L2	SW-W-0.47	.47 μ h									
				L3	SW-W-0.68	.68 μ h									
				L4	SW-W-0.68	.68 μ h									
				L5	SW-W-0.47	.47 μ h									
				L6	AEL	3 $\frac{1}{2}$ T 1/8" ID #18									
				L7	AEL	2 $\frac{1}{2}$ T 1/8" ID #18									
				L8	AEL	1 $\frac{1}{2}$ T 1/8" ID #18									
				L9	AEL	UT 34 $\approx$ 3"									
				L10	AEL	UT 34 $\approx$ 6"									
				L11	AEL	1 $\frac{1}{2}$ T 1/8" ID #18									
				L12		$\frac{1}{2}$ T 1/8" ID #18									
				L13		VK 200 -09/3B									
				VR1	GLA62	Zener Diode									
				VR2	1N757	Zener Diode									
				CR1	HP 5082-3039	Diode				HP					
				CR2	HP 5082-3039	Diode									
				CR3	HP 5082-3039	Diode									
				CR4	HP 5082-3039	Diode									
				CR5	HP 5082-3039	Diode									
				CR6	HP 5082-3039	Diode									



SCHEMATIC TITLE				SCHEMATIC DWG NO	
MDCP3					
ORIGINATOR	DATE	APPROVED E E	DATE	APPROVED M E	DATE

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III-19

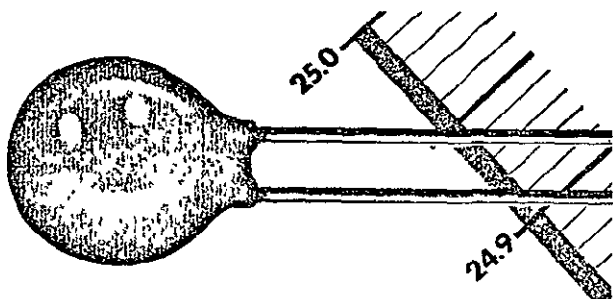
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III-20

APPENDIX IV

THERMISTER CHARACTERISTICS

Thermistors



WHAT IS A THERMISTOR?

A thermistor is a temperature sensitive semiconductor whose prime function is to provide a large resistance change when subjected to a relatively minute change in body temperature. Composed of metal oxides, they are scientifically formulated and selected under exacting laboratory control.

HOW ARE THERMISTORS USED?

A thermistor is employed as a precision sensing element in any of the following applications:

Temperature Measurement	Time Delay
Temperature Control	Remote Control
Temperature Compensation	Switching
Safety & Warning Circuits	Voltage Control
Liquid Level Measurement	Altimeter Use
Power Level Control	Power Measurement

WHAT ARE THE IMPORTANT CHARACTERISTICS OF THERMOCERAM THERMISTORS?

High Stability	High Reliability
Close Tolerances	Extended Life
Small Size	R-T Characteristics
Fast Time Response	
Extremely High Temperature Coefficients	

High Stability — this is an inherent characteristic of THERMOCERAM thermistors. Advantages accruing to users include a significant reduction of maintenance and recalibration expenses.

Close Resistance Tolerance — up to $\pm 1\%$, matched pairs to $\pm 1\%$ and resistance ratios of $\pm 0.5\%$.

Small Size — of 0.050 diameter with time constant as low as 0.4 seconds with precision tolerances. (This characteristic makes it possible to replace bead type with disc thermistors.)

Thermistors produced by the CAL-R Thermometrics Division represent a significant advance in thermal sensing devices. By employing proprietary metallurgical engineering concepts during a decade of research and development, a new thermal sensing material has resulted with the name of THERMOCERAM. Performance characteristics provided with this new material not only permit improved design flexibility but make possible closer tolerances in such applications found in the military, aerospace and industrial electronic systems.

High Reliability — because of a continual program of product improvement and by employing close quality control systems with the latest electronic and laboratory equipment, each thermistor adheres to product specifications.

Extended Life — virtually unlimited operating life when operated within designated performance specifications.

Infinite Variations — Innumerable combinations are available for resistance, temperature coefficient, size, geometry, lead wires, protective coatings, encapsulation and mechanical configurations.

Large Resistance Changes — greater than 10 million to 1 are possible in thermistors as compared to platinum's change in resistance of less than 10 to 1 over the same temperature range — reference Fig. 1.

Resistance — Temperature (R-T) Characteristics — Thermistor resistance is a function of its absolute temperature. Resistance measurements are made with essentially zero power dissipation by the thermistor. Relationship between thermistor resistance and its absolute temperature is expressed as —

$$\frac{R_o(T)}{R_o(T_o)} = e^{\beta \left(\frac{1}{T} - \frac{1}{T_o} \right)}$$

Where

$R_o(T)$ = Resistance at absolute temperature T

$R_o(T_o)$ = Resistance at absolute temperature T_o

e = 2.718 (Napierian base)

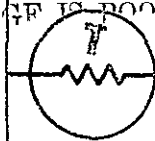
β = Thermistor material constant

The temperature coefficient of resistance (α) is expressed as α per $^{\circ}\text{C}$ or as ohms/ohm/ $^{\circ}\text{C}$ as follows —

$$\alpha = \frac{1}{R_o} \frac{dR}{dT}$$

$$\text{which is approximately } \alpha = -\frac{\beta}{T^2}$$

thermonetics



4 - SERIES
THERMISTORS
25 to 500

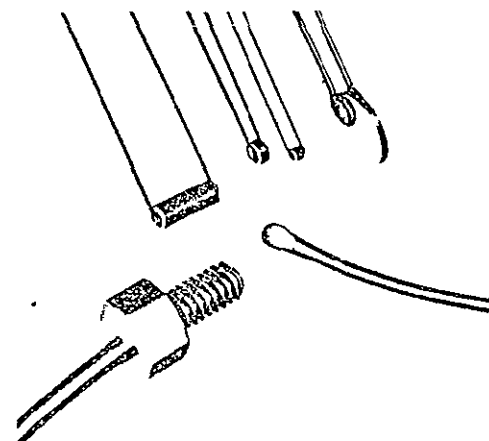
COMPOSITION "B" DISC THERMISTORS

Composition "B" thermistors are part of a family of thermal sensors representing a new breakthrough in materials engineering. After more than a decade of engineering development and a constant product improvement, CAL-R Thermionetics Division has formulated a new thermal sensing material called THERMOCERAM. The "B" composition offers a broad range of resistance values. The design engineer can specify from 25 to 500Ω from the same basic type of thermistor. In addition to this wide range of values, the "B" series is an excellent, highly stable, broad application thermal sensor that finds use in innumerable heat sensing designs.

All "B" series thermistors conform to AQL and confidence levels as specified in MIL-T-23648 as outlined by tables V & VI.

Coatings, encapsulations, markings, probes and resistor/thermistor networks . . . are also available to meet specific requirements by contacting our application engineering department.

Resistance tolerances of $\pm 1\%$ thru $\pm 20\%$ are available and may be specified at 25°C, or any temperature within the operating range.



SPECIFICATIONS

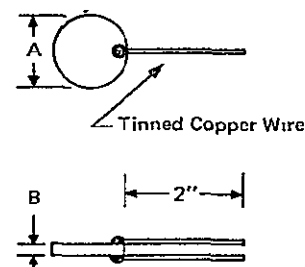
1 R at 25°C ±10%	2 Thermo P/N	3 D.C.*	4 T.C.**	5 Dim.		6 Leads AWG#
				"A"	"B"	
500	1B07	2	3	.05	.08	30
400	1B08	2	3	.05	.07	30
300	1B09	2	3	.05	.05	30
250	1B095	2	2	.05	.04	30
200	1B10	2	2	.05	.03	30
150	1B11	2	2	.05	.025	30
100	1B12	2	2	.05	.020	30
300	1B120	2.5	5	.07	.100	30
250	1B125	2	4.5	.07	.085	30
200	1B110	2	4	.07	.07	30
150	1B111	2	3	.07	.05	30
100	1B112	2	3	.07	.03	30
150	1B113	4	14	.10	.10	28
125	1B115	4	12	.10	.085	28
100	1B13	3	10	.10	.070	28
80	1B14	3	8	.10	.05	28
70	1B145	3	7	.10	.045	28
60	1B147	3	7	.10	.04	28
50	1B15	3	6	.10	.03	28
40	1B165	3	5	.10	.03	28
30	1B16	3	5	.10	.02	28
100	1B151	7	30	.15	.15	24
75	1B152	7	25	.15	.10	24
50	1B153	7	20	.15	.075	24
25	1B154	7	18	.15	.04	24
80	1B118	8	40	.20	.20	24
75	1B117	8	36	.20	.19	24
50	1B18	7	30	.20	.13	24
30	1B19	7	25	.20	.08	24
20	1B20	7	20	.20	.05	24
15	1B205	7	19	.20	.04	24
10	1B21	7	18	.20	.03	24
30	1B22	9	75	.30	.18	24
20	1B225	8.5	60	.30	.12	24
10	1B23	8	48	.30	.06	24
7.5	1B235	8	42	.30	.045	24
5	1B24	8	35	.30	.03	24
15	1B119	10	85	.40	.16	22
12.5	1B265	10	77	.40	.13	22
10	1B26	9	70	.40	.10	22
7.5	1B27	9	65	.40	.08	22
5	1B28	9	50	.40	.05	22
2.5	1B33	14	60	.50	.04	22

APPLICATIONS

~ Engineered for

- Temperature Compensation
- Temperature Measurement
- Temperature Control
- Meter Compensation
- Voltage Regulation
- Amplitude Control
- Liquid Level Indication
- Flow Measurement
- Surge Suppression
- Time Delay

BASIC FORMAT



*DISSIPATION CONSTANT

Dissipation Constant, expressed in mw/°C, represents the amount of power required to raise the temperature of a thermistor 1°C.

**TIME CONSTANT

Time Constant, expressed in seconds, is the time required for a thermistor dissipating zero power to change 63% of the difference between its initial temperature value and that of a new temperature environment.

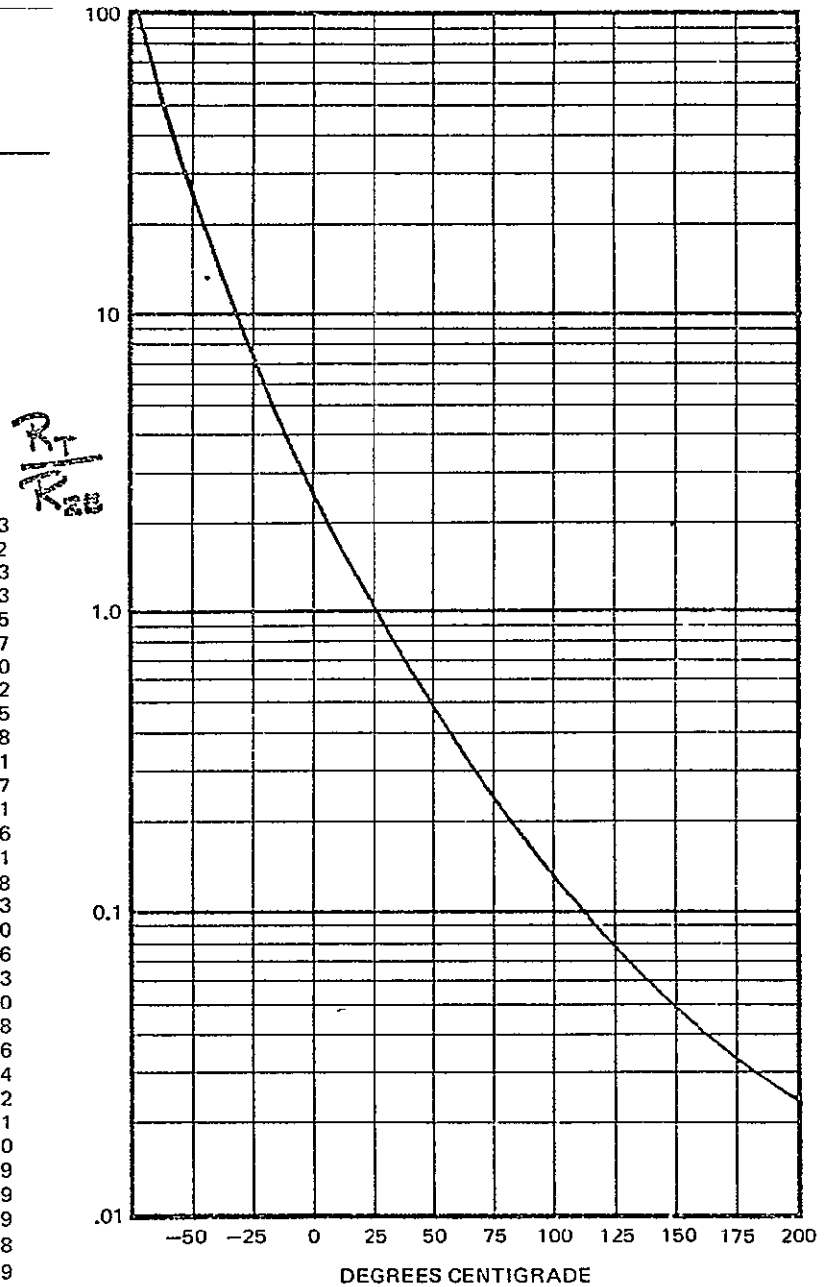
TEMPERATURE CONVERSION INFORMATION

"B" R/T CONVERSION TABLE

Ratio $\frac{R @ 0^{\circ}\text{C}}{R @ 50^{\circ}\text{C}}$ $5.3 \pm 3\%$
 Temp Coef @ 25°C $-3.3\%/^{\circ}\text{C}$
 Beta (25 to 75°C) 3000°K

-60	-43.0	-7	-3.25	+46	-522	+99	-133
59	-40.4	6	-3.12	47	-.507	100	-.130
58	-38.0	5	-2.99	48	-.492	101	-.127
57	-35.8	4	-2.87	49	-.477	102	-.124
56	-33.8	3	-2.76	50	-.464	103	-.122
55	-31.9	2	-2.65	51	-.452	104	-.119
54	-30.2	-1	-2.55	52	-.438	104.4	-.118
53	-28.6	0	-2.45	53	-.426	105	-.117
52	-27.1	+1	-2.36	54	-.414	106	-.114
51	-25.7	2	-2.27	55	-.403	107	-.112
50	-24.3	3	-2.18	56	-.393	108	-.109
49	-23.0	4	-2.10	57	-.382	109	-.107
48	-21.8	5	-2.02	58	-.372	110	-.105
47	-20.7	6	-1.95	59	-.361	111	-.103
46	-19.6	7	-1.88	60	-.350	112	-.101
45	-18.6	8	-1.81	61	-.342	113	-.0983
44	-17.6	9	-1.74	62	-.332	114	-.0962
43	-16.7	10	-1.68	63	-.323	115	-.0943
42	-15.9	11	-1.62	64	-.313	116	-.0923
41	-15.1	12	-1.57	65	-.305	117	-.0905
40	-14.4	13	-1.52	66	-.297	118	-.0887
39	-13.7	14	-1.47	67	-.289	119	-.0870
38	-13.1	15	-1.42	68	-.282	120	-.0852
37	-12.5	16	-1.37	69	-.274	121	-.0835
36	-11.8	17	-1.32	70	-.267	122	-.0818
35	-11.3	18	-1.27	71	-.261	123	-.0801
34	-10.8	19	-1.22	72	-.254	124	-.0787
33	-10.3	20	-1.18	73	-.248	125	-.0771
32	-9.79	21	-1.14	74	-.242	126	-.0756
31	-9.32	22	-1.11	75	-.236	127	-.0741
30	-8.93	23	-1.07	76	-.229	128	-.0728
29	-8.51	24	-1.03	77	-.224	129	-.0713
28	-8.12	25	-1.00	78	-.218	130	-.0700
27	-7.78	26	-.970	79	-.213	131	-.0686
26	-7.41	27	-.939	80	-.208	132	-.0673
25	-7.10	28	-.910	81	-.203	133	-.0660
24	-6.80	29	-.881	82	-.198	134	-.0648
23	-6.49	30	-.854	83	-.193	135	-.0636
22	-6.21	31	-.828	84	-.188	136	-.0624
21.5	-6.09	32	-.802	85	-.183	137	-.0612
21	-5.93	33	-.779	86	-.179	138	-.0601
20	-5.69	34	-.756	87	-.175	139	-.0590
19	-5.43	35	-.732	88	-.171	140	-.0579
18	-5.20	36	-.710	89	-.167	141	-.0569
17	-4.98	37	-.689	90	-.163	142	-.0559
16	-4.75	37.8	-.671	91	-.159	143	-.0548
15	-4.56	38	-.668	92	-.156	144	-.0539
14	-4.37	39	-.647	93	-.152	145	-.0529
13	-4.18	40	-.628	94	-.148	146	-.0520
12	-4.01	41	-.608	95	-.145	147	-.0511
11	-3.84	42	-.589	96	-.142	148	-.0501
10	-3.68	43	-.571	97	-.139	149	-.0492
9	-3.52	44	-.554	+98	-.136	+150	-.0483
8	-3.39	+45	-.537				

REPRODUCIBILITY OF THE
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 RESISTANCE - TEMPERATURE CURVE



To determine the resistance of a thermistor at a specified temperature, multiply the thermistor resistance @ 25°C by the factor opposite the desired temperature

Contact the plant for application assistance. Chances are we may have already supplied thermistors for similar applications
 Our technical staff will be pleased to help you